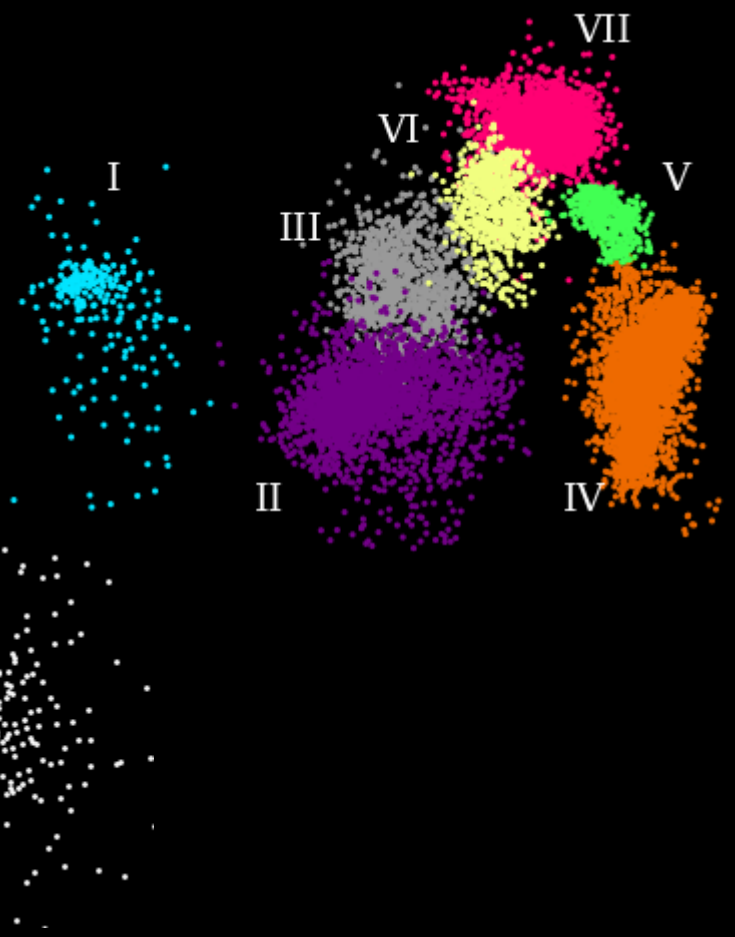
Gaia reveals the 7D structure of the young cluster population in Vela-Puppis

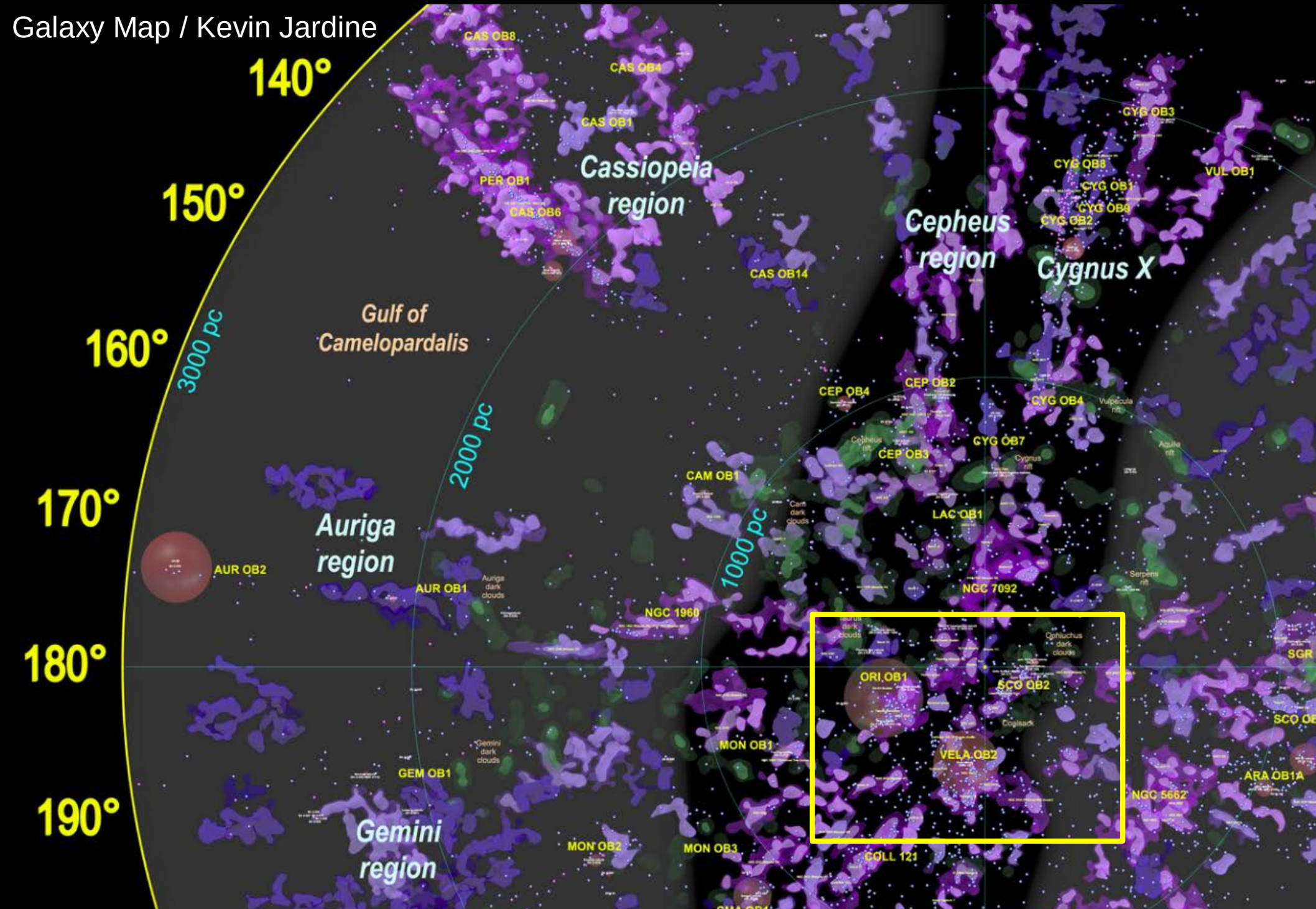


Tristan Cantat-Gaudin

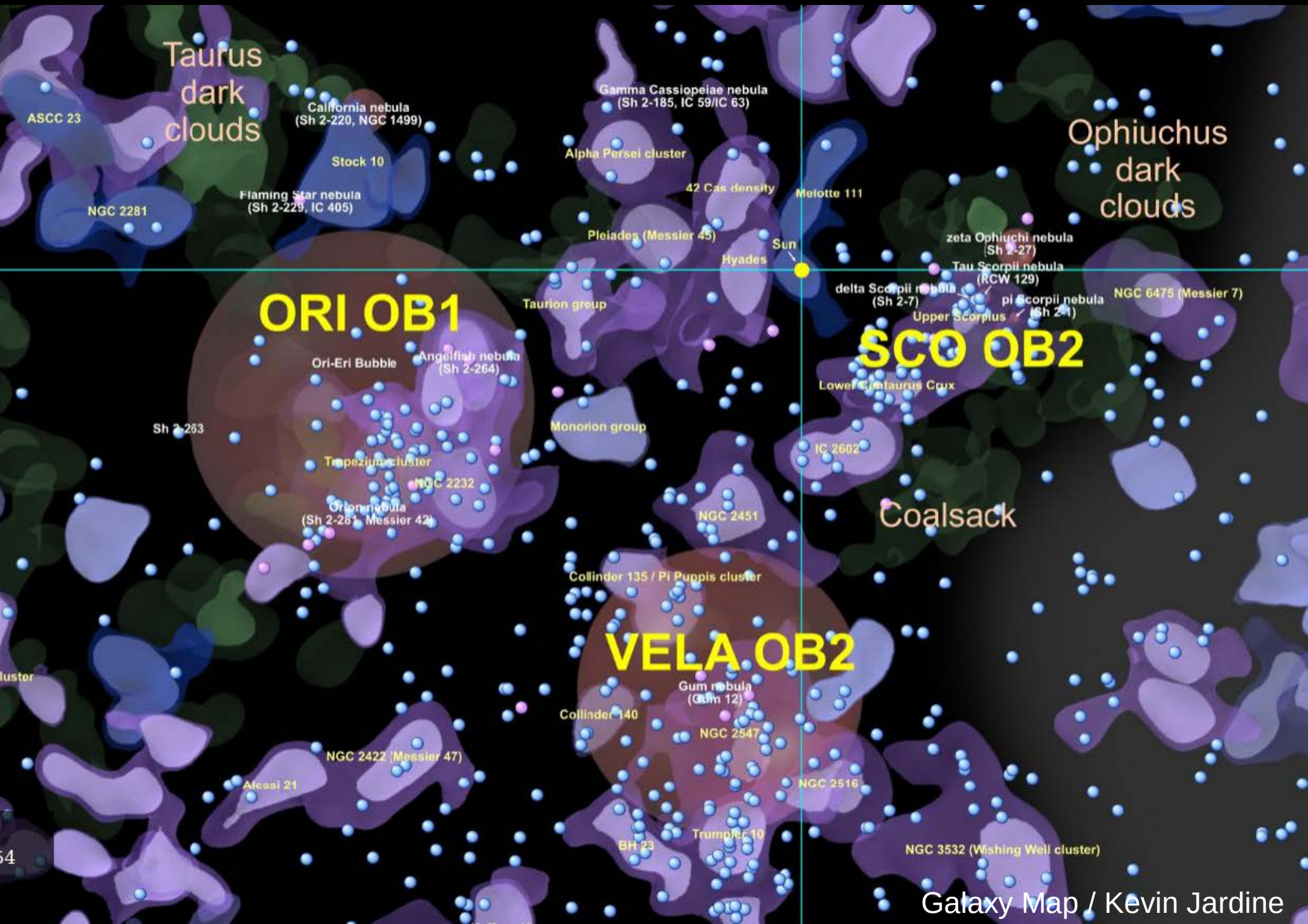
StarFormMapper Final Conference
16th – 20th September 2019, York (UK)

ICCUB
Universitat de Barcelona

Galaxy Map / Kevin Jardine



Small-scale structure in the solar neighbourhood



Galaxy Map / Kevin Jardine

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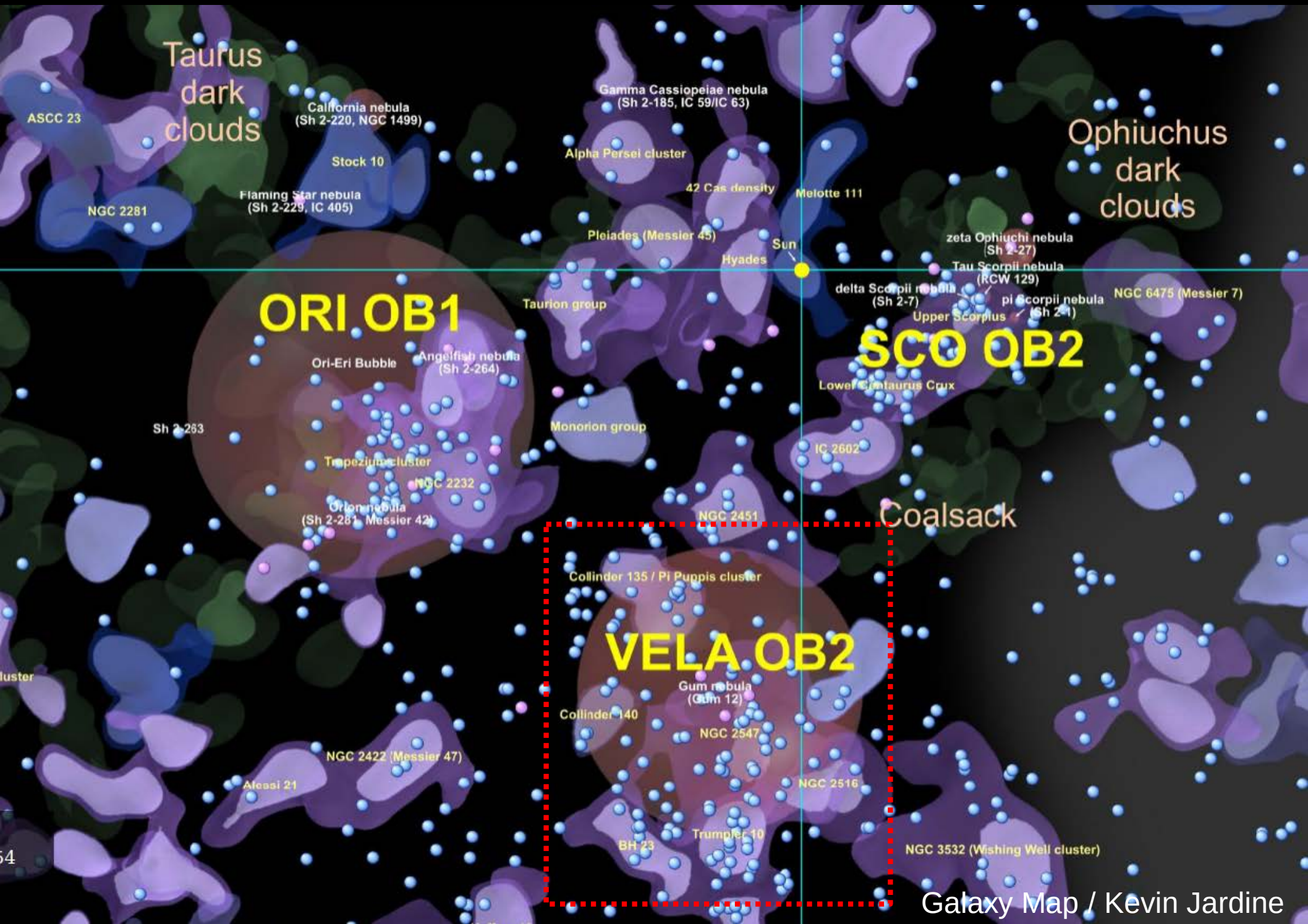
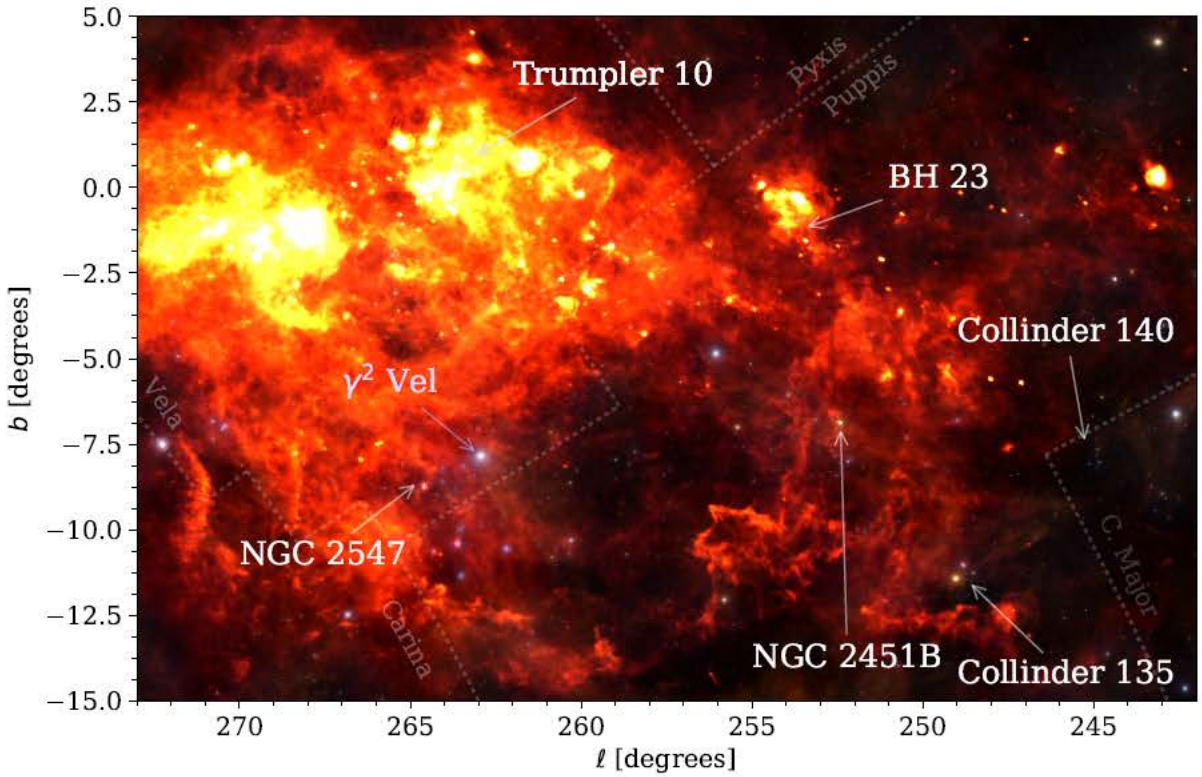


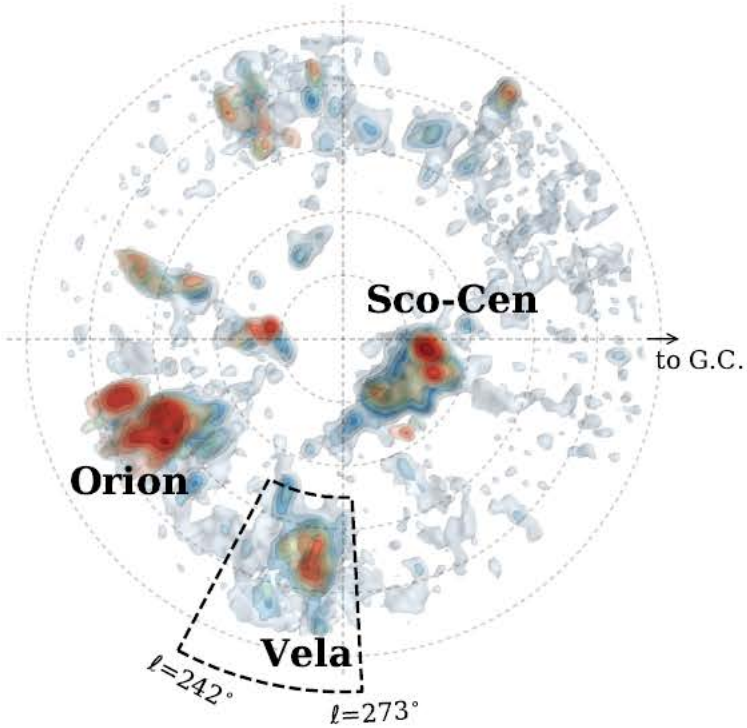
Galaxy Map / Kevin Jardine

Conclusion

This stellar complex shows convincing evidence for having been the stage of an episode of supernova-sustained turbulence, with multiple bursts of star formation.

The Vela-Puppis region

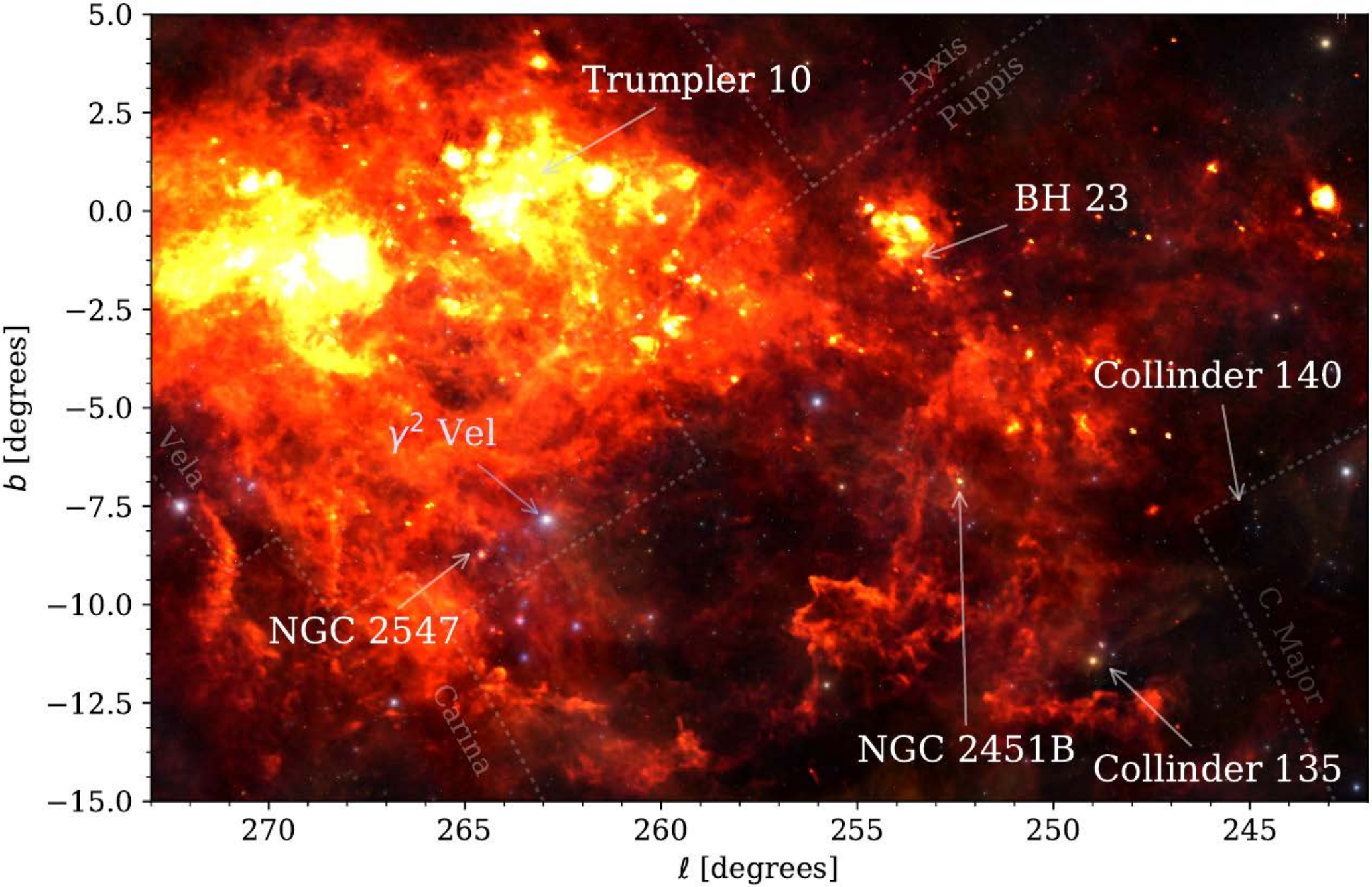




[Zari et al. 2018]

The Vela-Puppis region

Several known young OCs (~20-50 Myr). Complex background. Expanding dust/gas shell.



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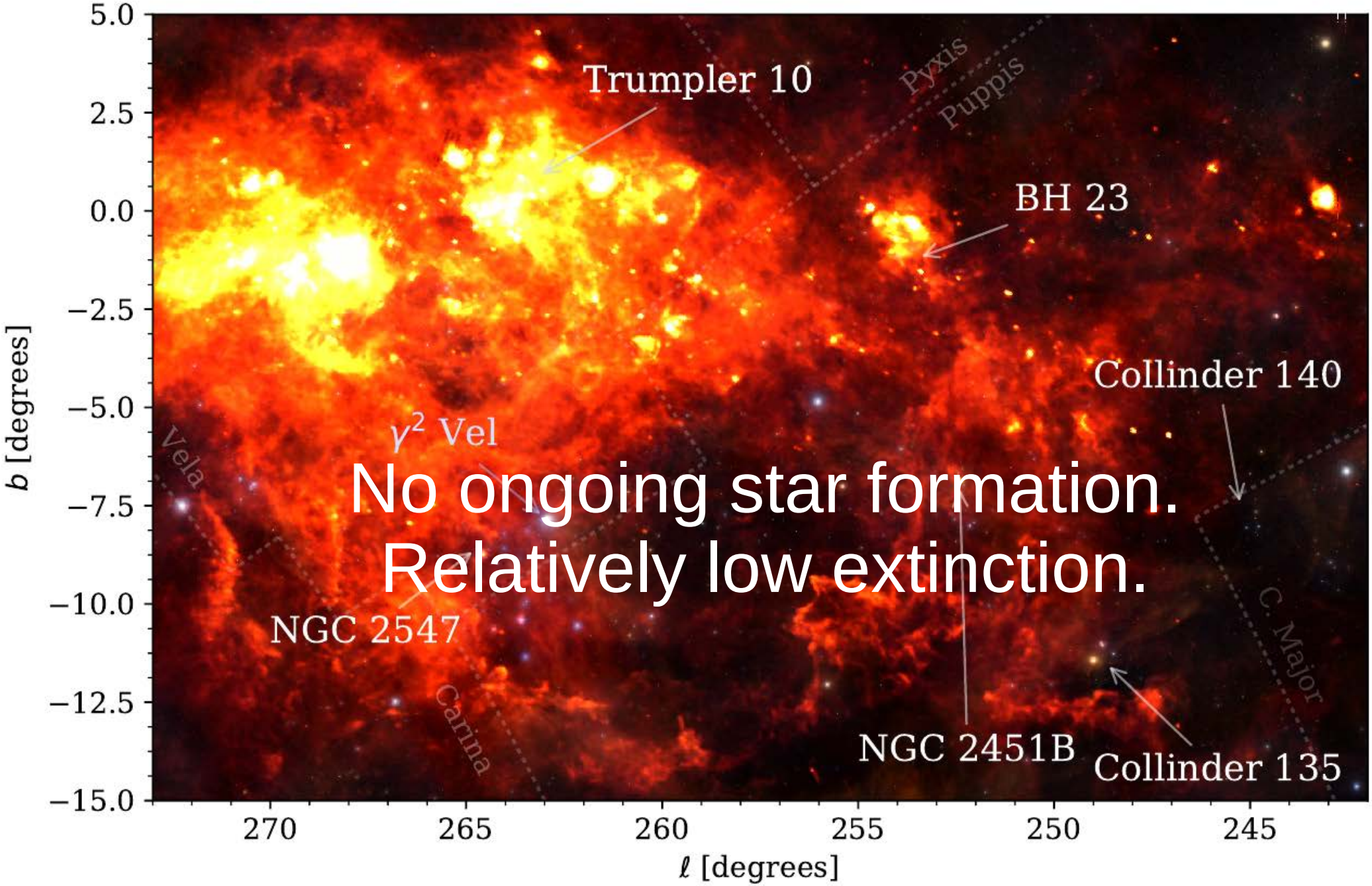

No ongoing star formation.
Relatively low extinction.

The Vela-Puppis region

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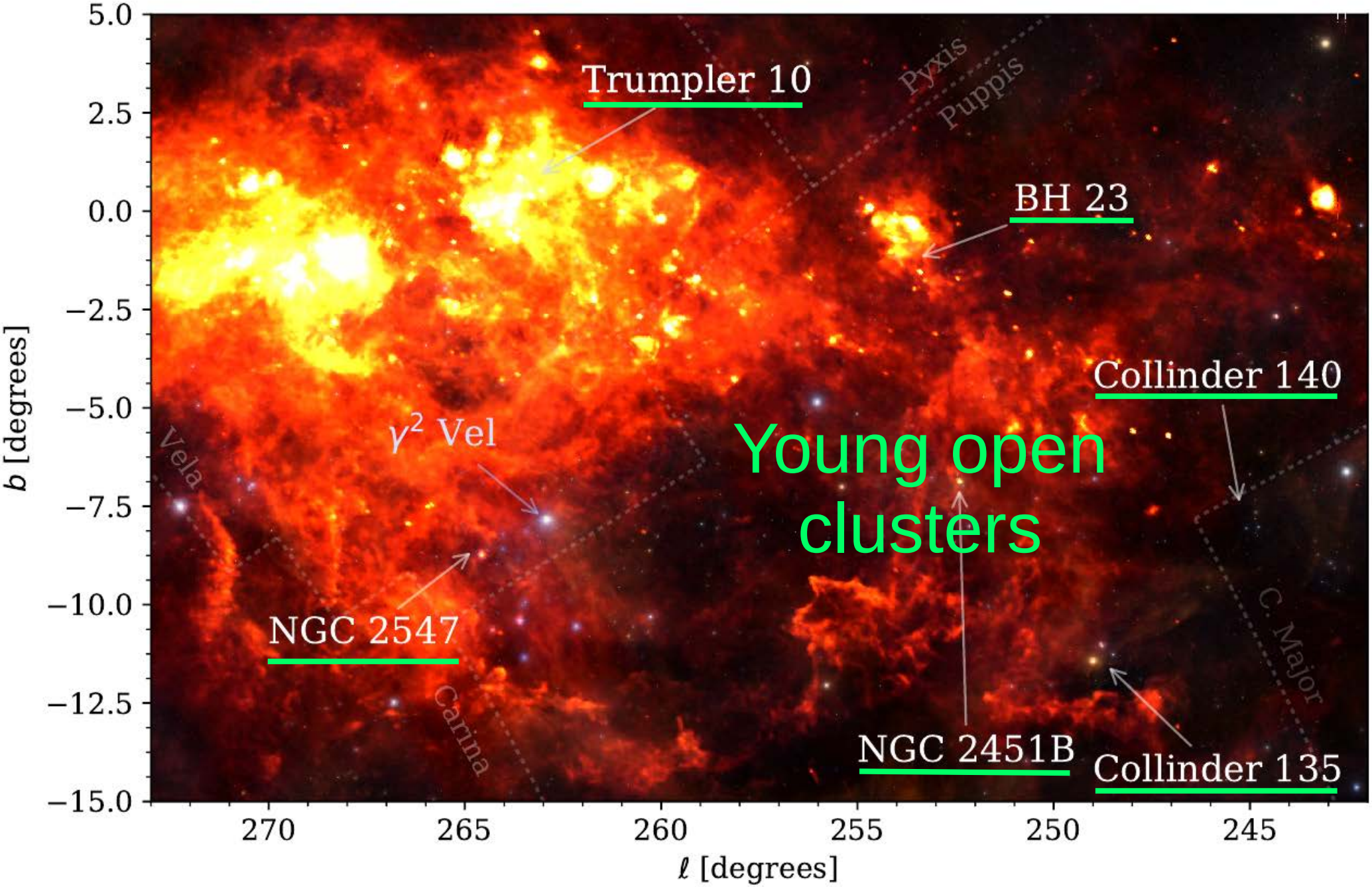

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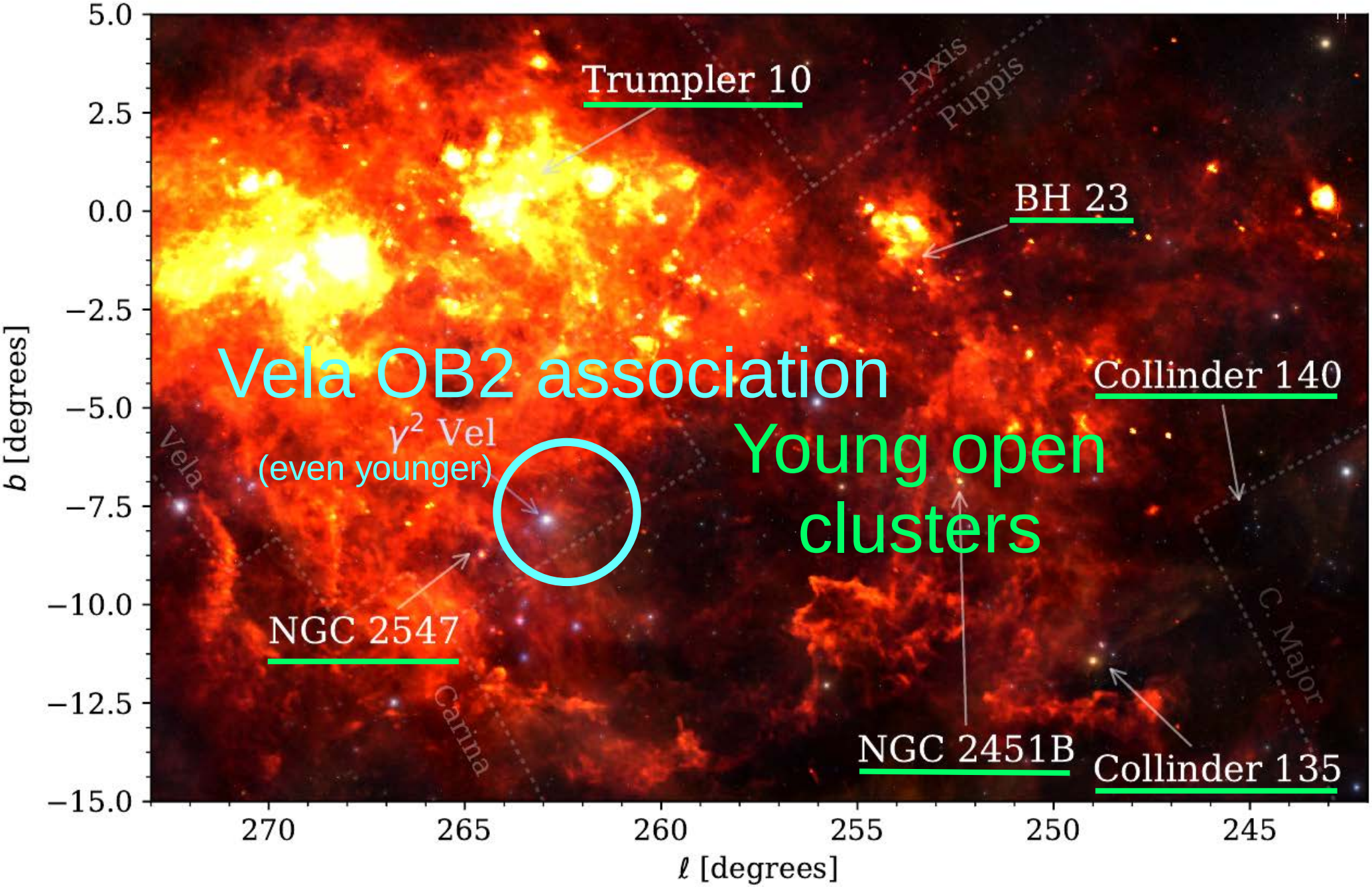

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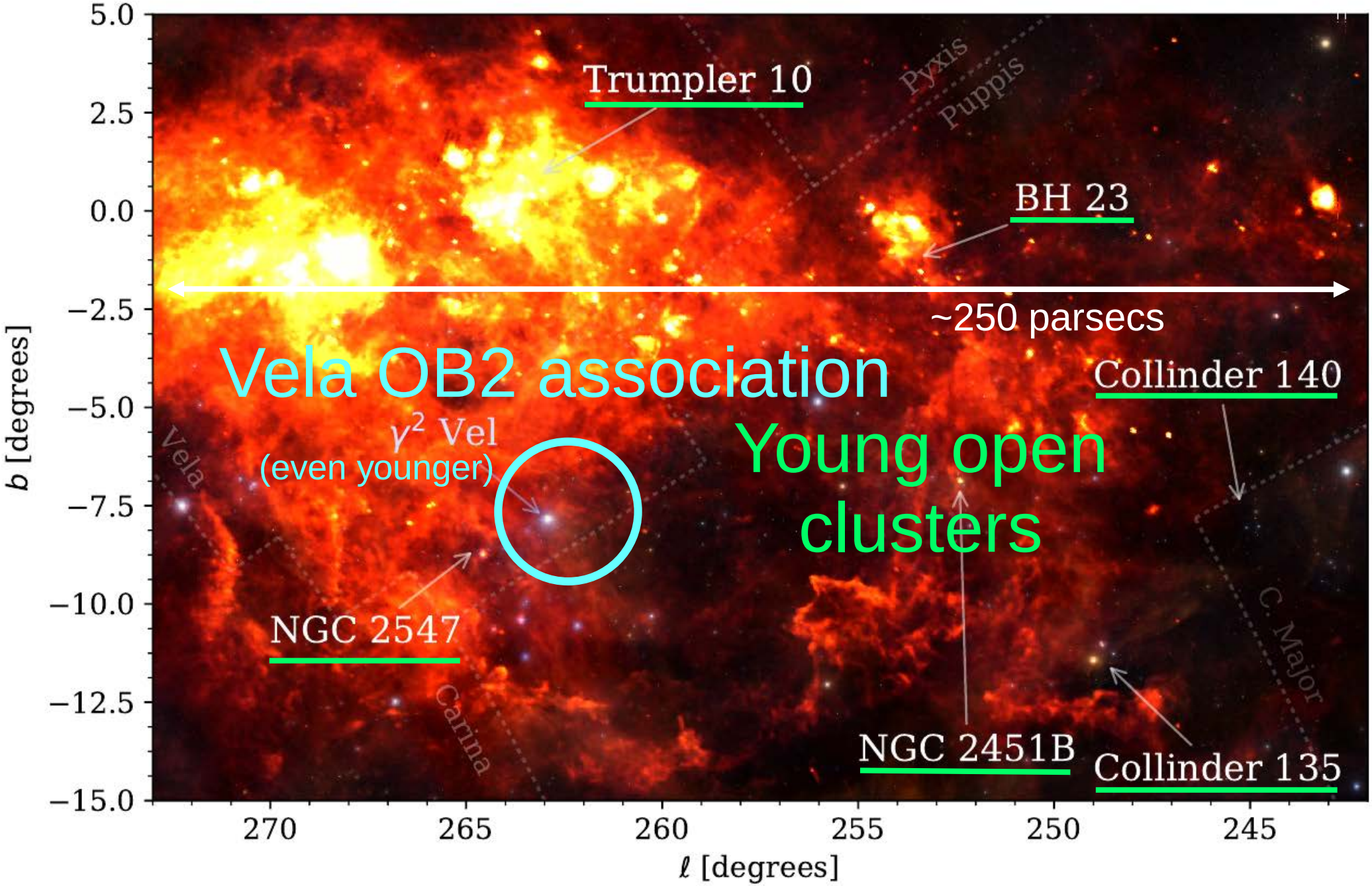
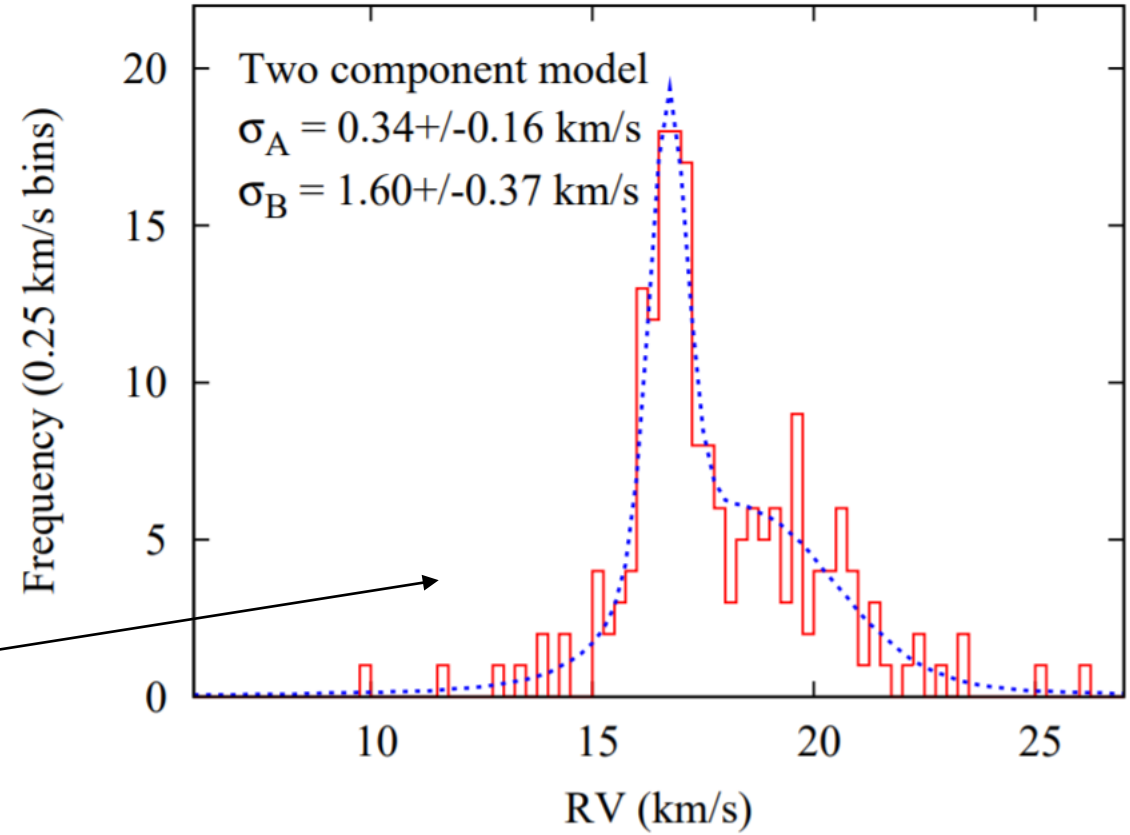


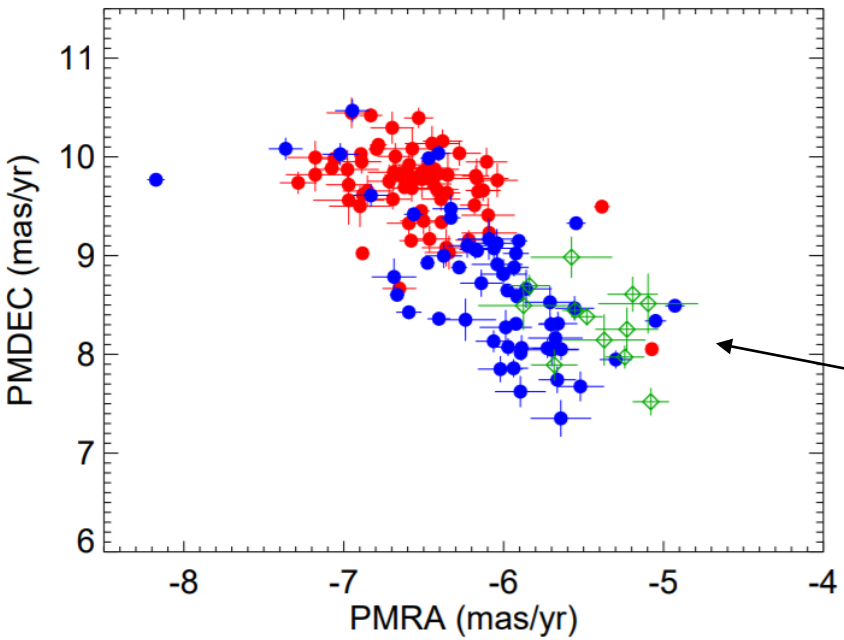
The “Gamma Velorum cluster(s)”

The Gamma2 Vel. star is in fact a massive binary system made up of a WR star and an O-type star.

Pozzo et al. (2000) identified a group of pre-main sequence stars surrounding it, but it was not clear how such a massive systen could form in such a low-density environment.

Jeffries et al. (2014) noticed a bi-modal radial velocity distribution.





Confirmed by Gaia DR2 proper motions and parallaxes (Franciosini et al. 2018).

The Vela-Puppis region

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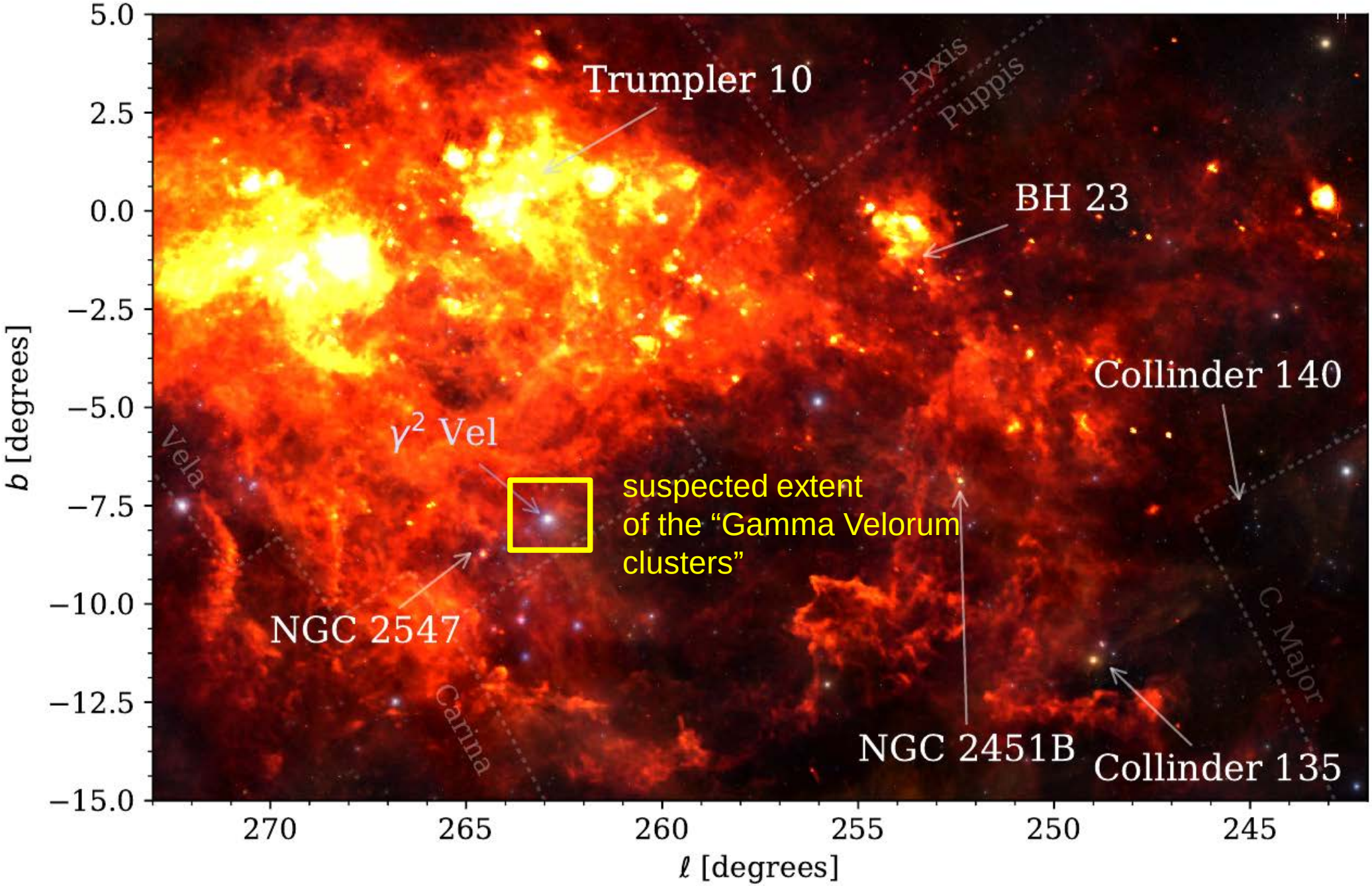

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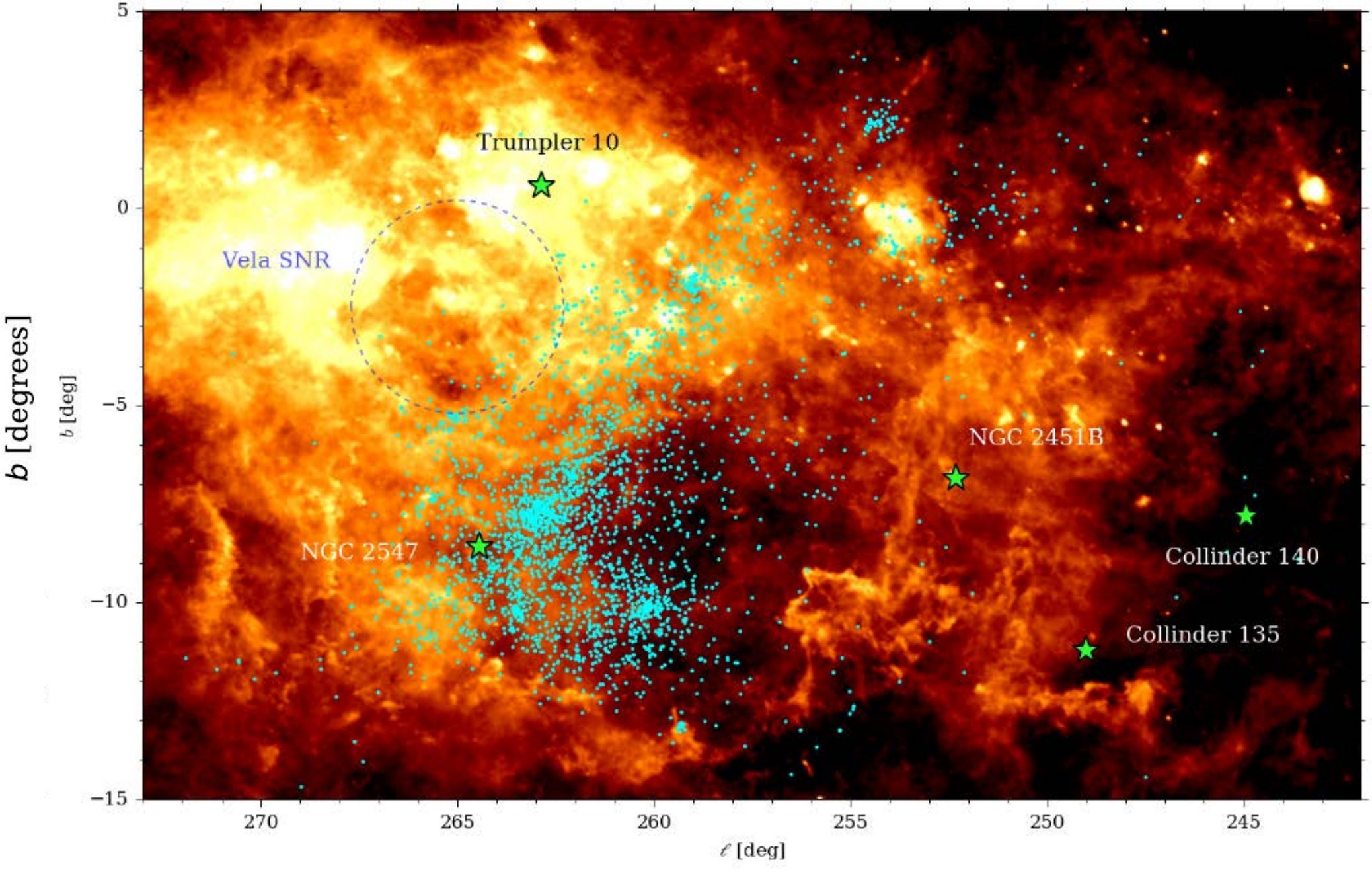
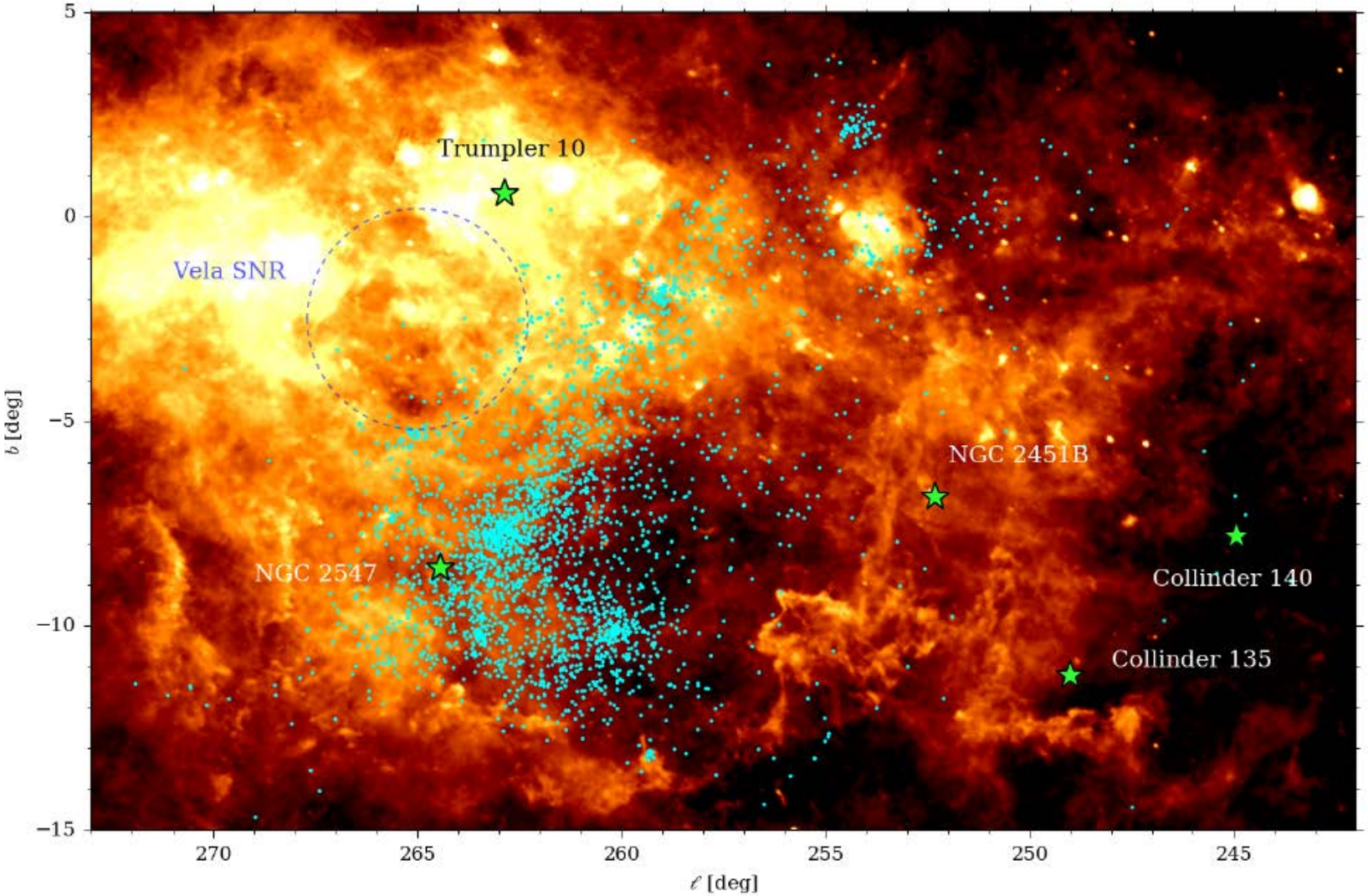


Initially trying to characterise the Vela OB2 association

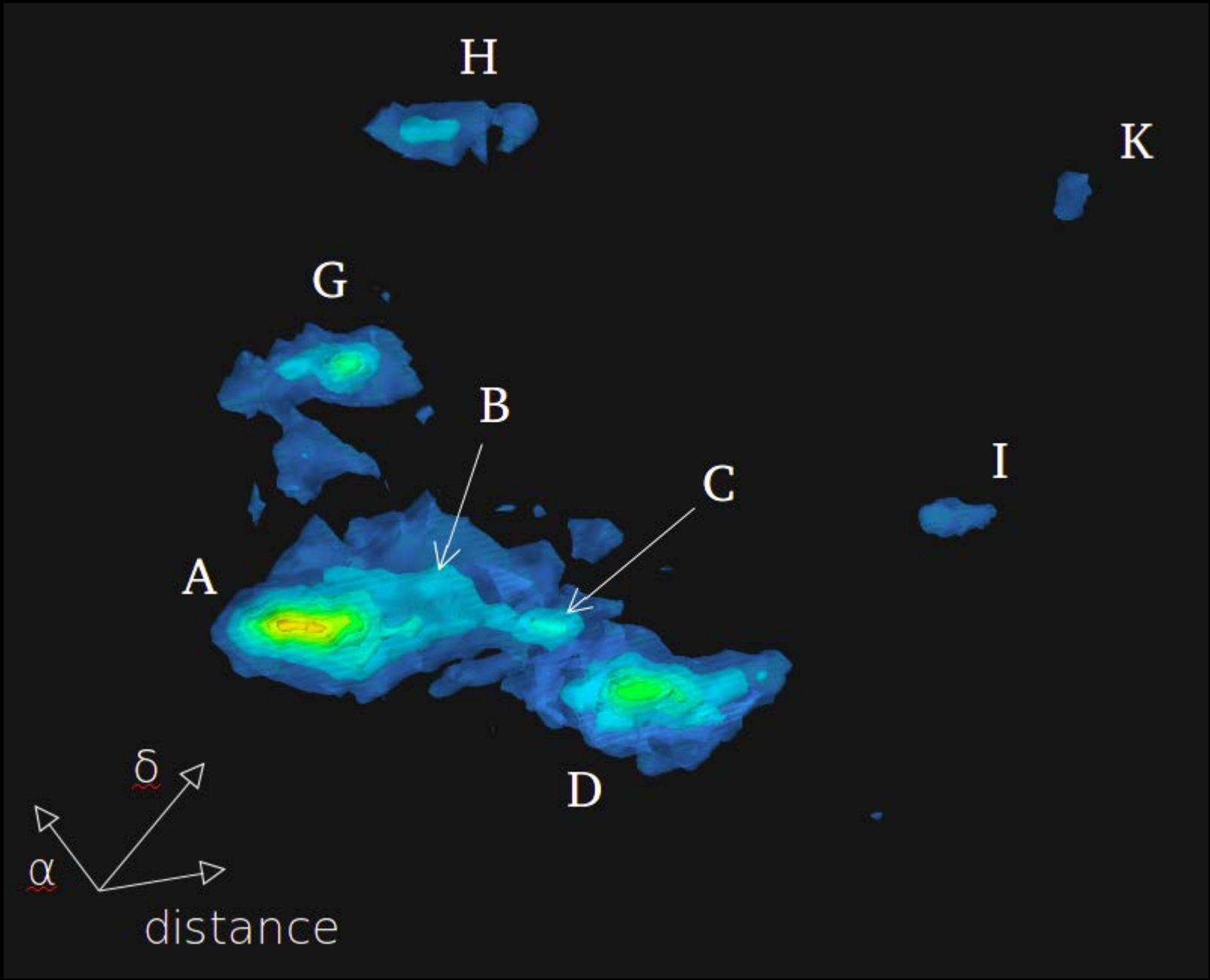
Looking for stars with the same age and kinematics as Vela OB2 we found not just two, but at least 11 different clumps over a large area! Most of these stars are not O or B stars, but pre-main sequence stars.



These stars roughly follow the edge of the structure known as the IRAS Vela Shell.

And their overall structure is expanding!

[Cantat-Gaudin et al. 2019, A&A 621 115]

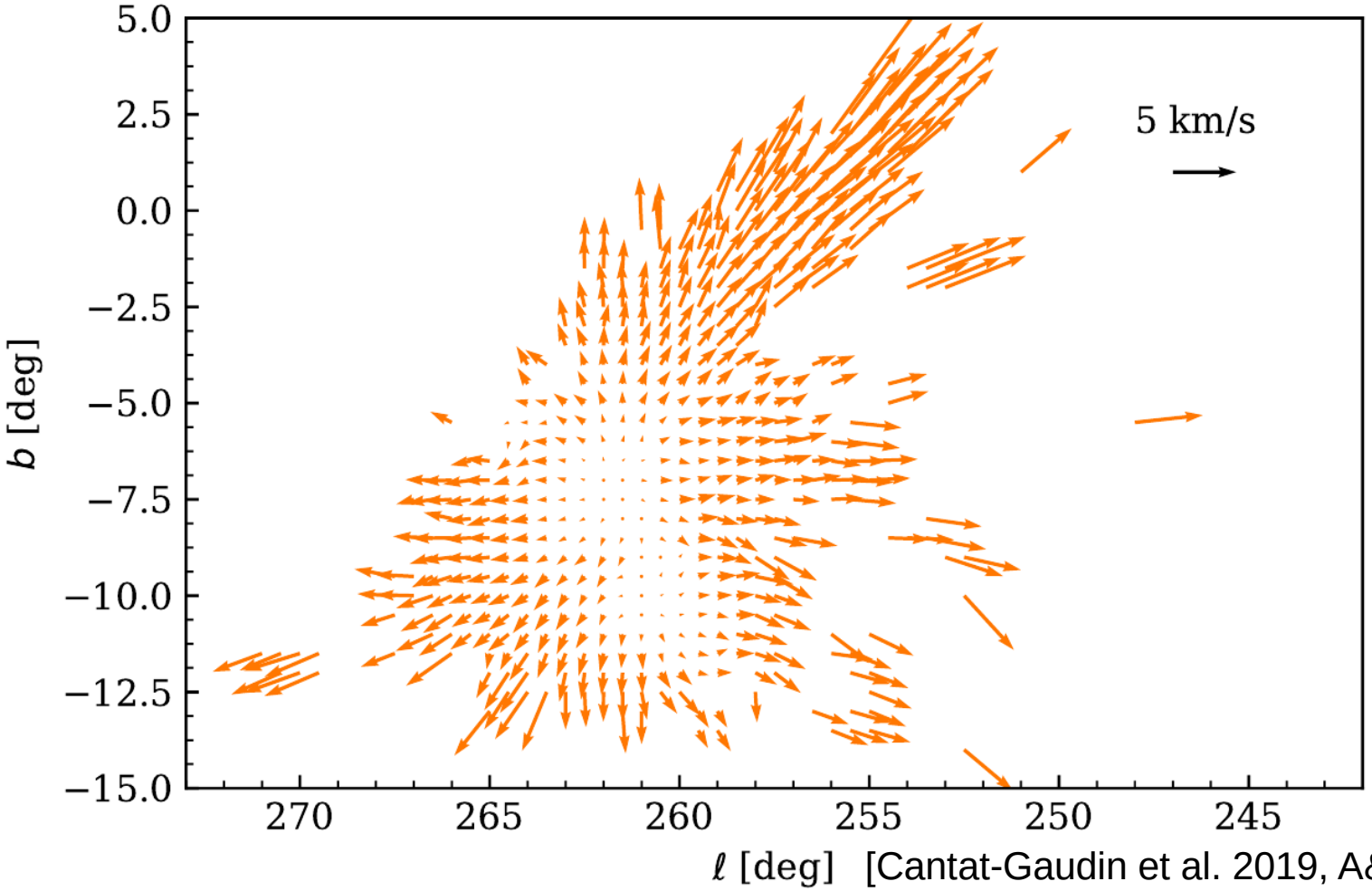

H
K
G
B
I
C
A
D
δ
α
distance

Kinematics inside the “Vela OB2 association”

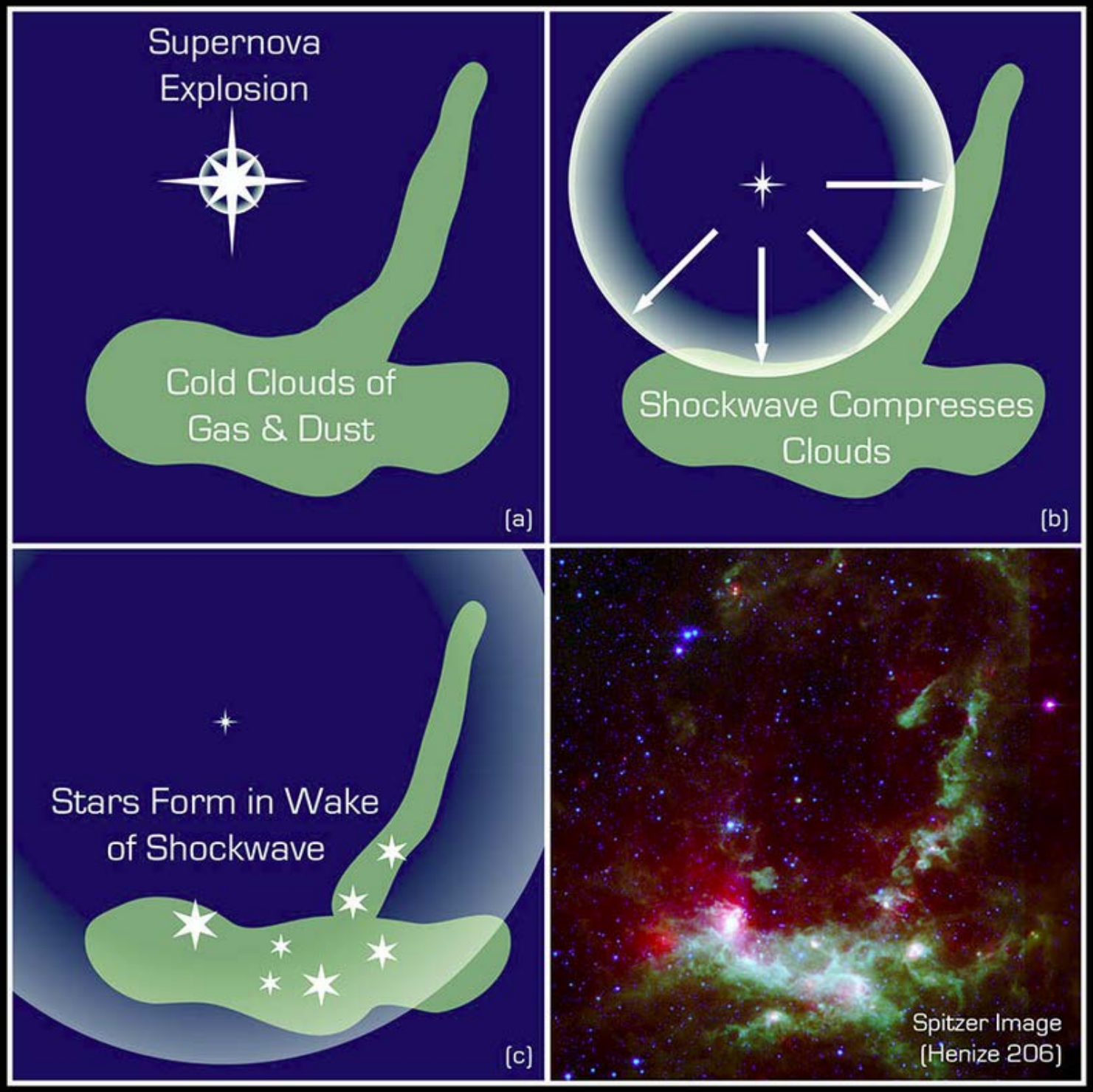
The whole system is very clearly expanding.

Some of the denser clumps might remain bound?

The rest of the stars will probably just disperse and join the “field population”.

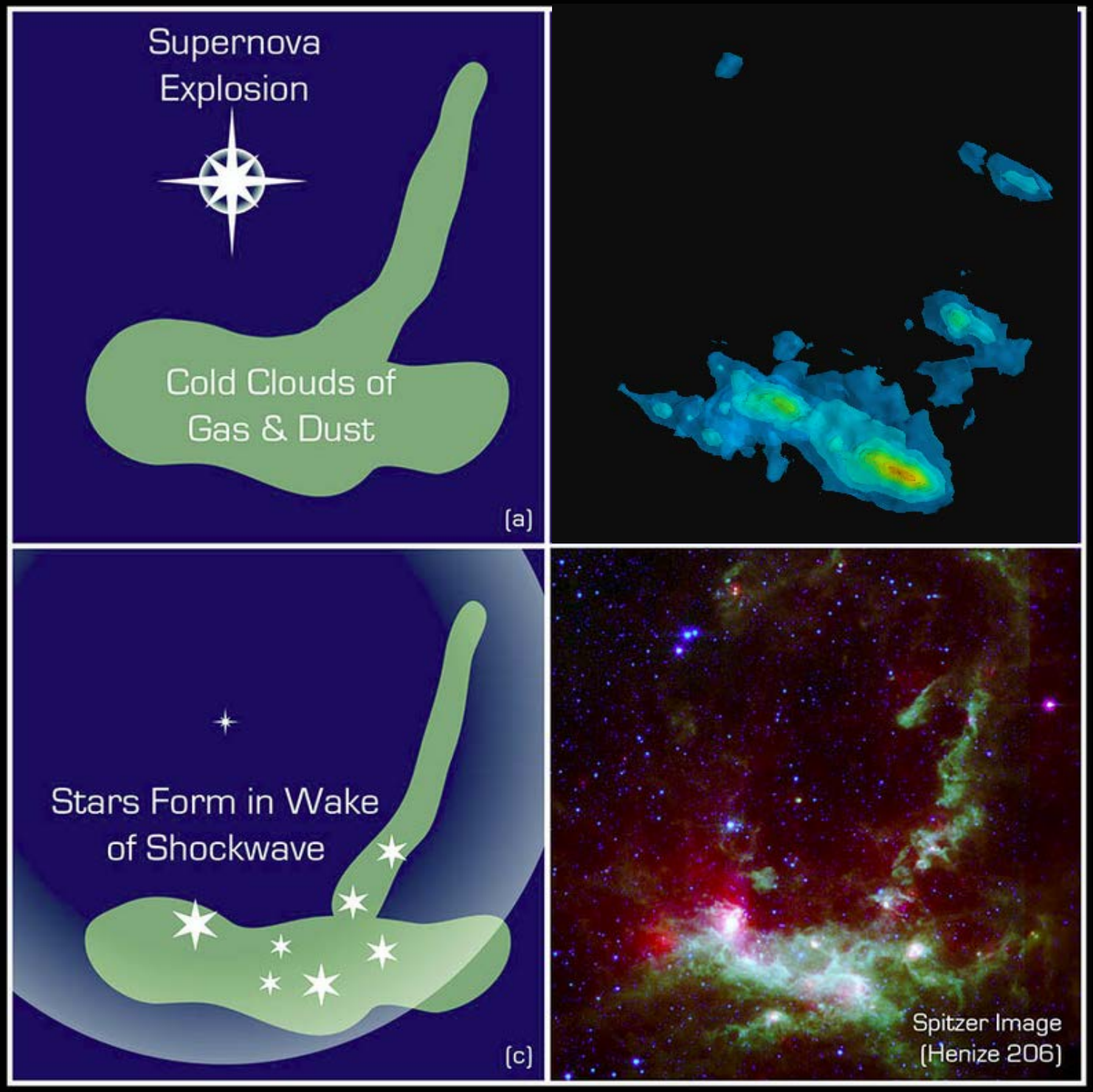


[Cantat-Gaudin et al. 2019, A&A 626 17]



Star forming region Henize 206 (in the LMC)

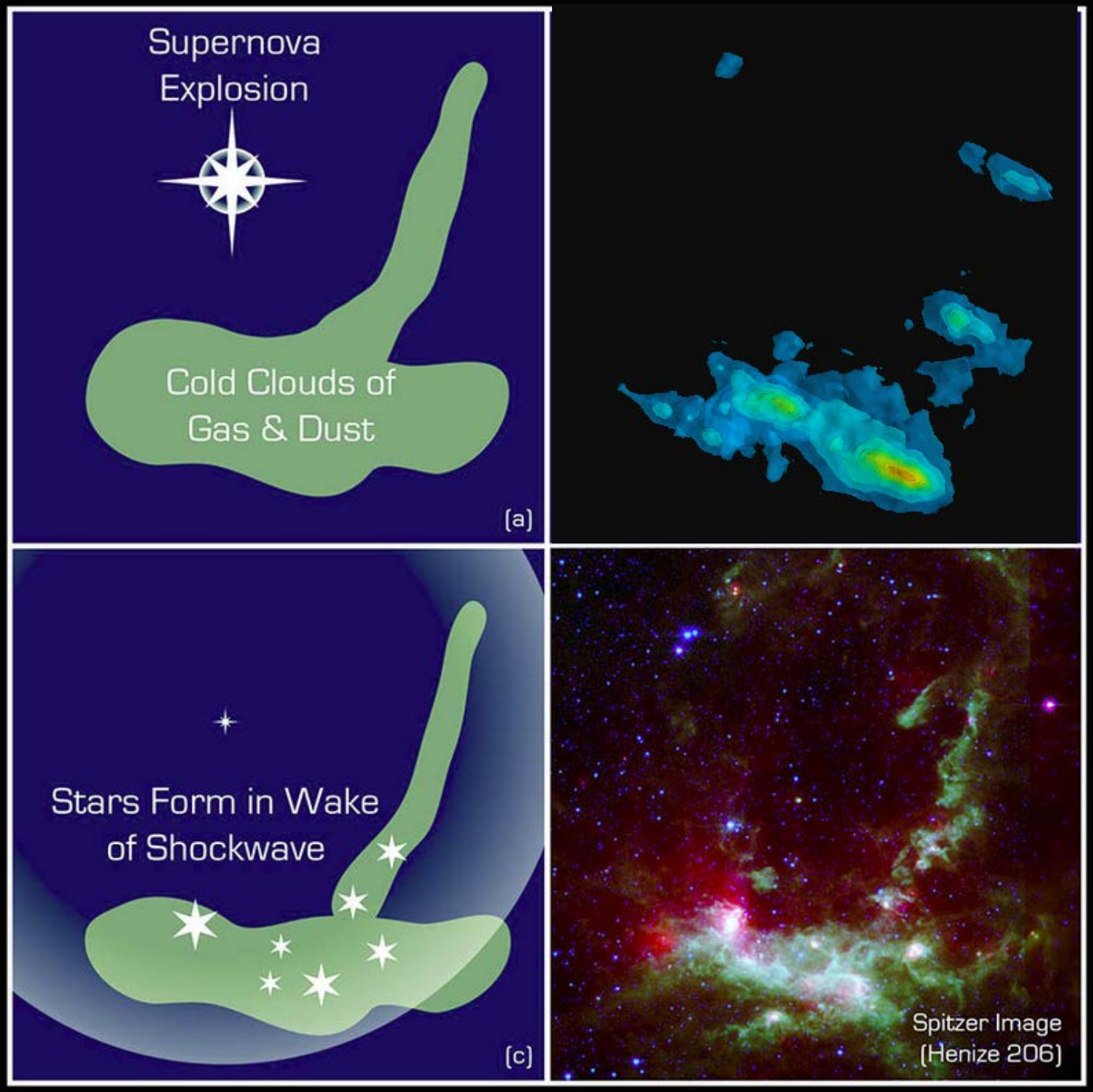
Credit: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)



Star forming region Henize 206 (in the LMC)

Plausible scenario for the Vela OB2 association if we could prove a Supernova event took place at the right place and time.

Credit: NASA/JPL-Caltech/R. Hurt (SSC-Caltech)



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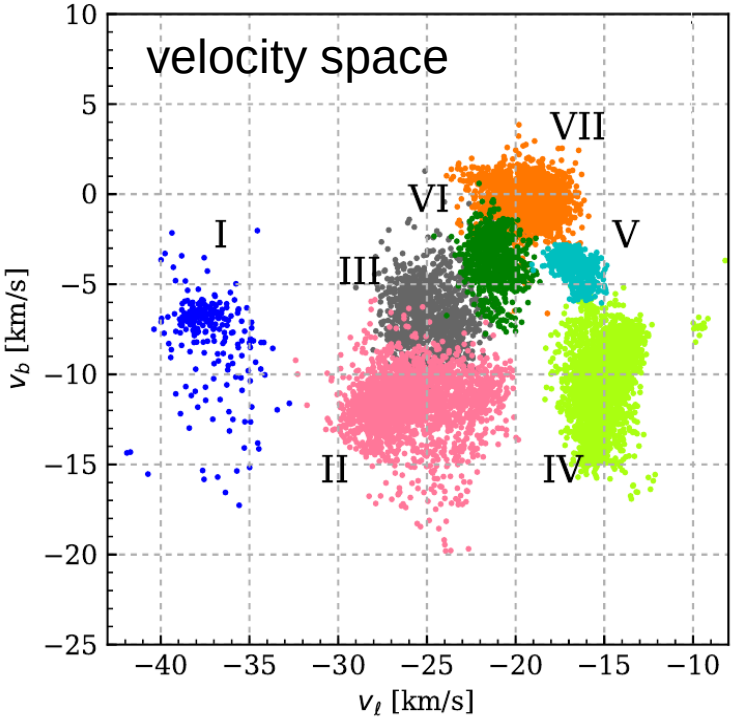
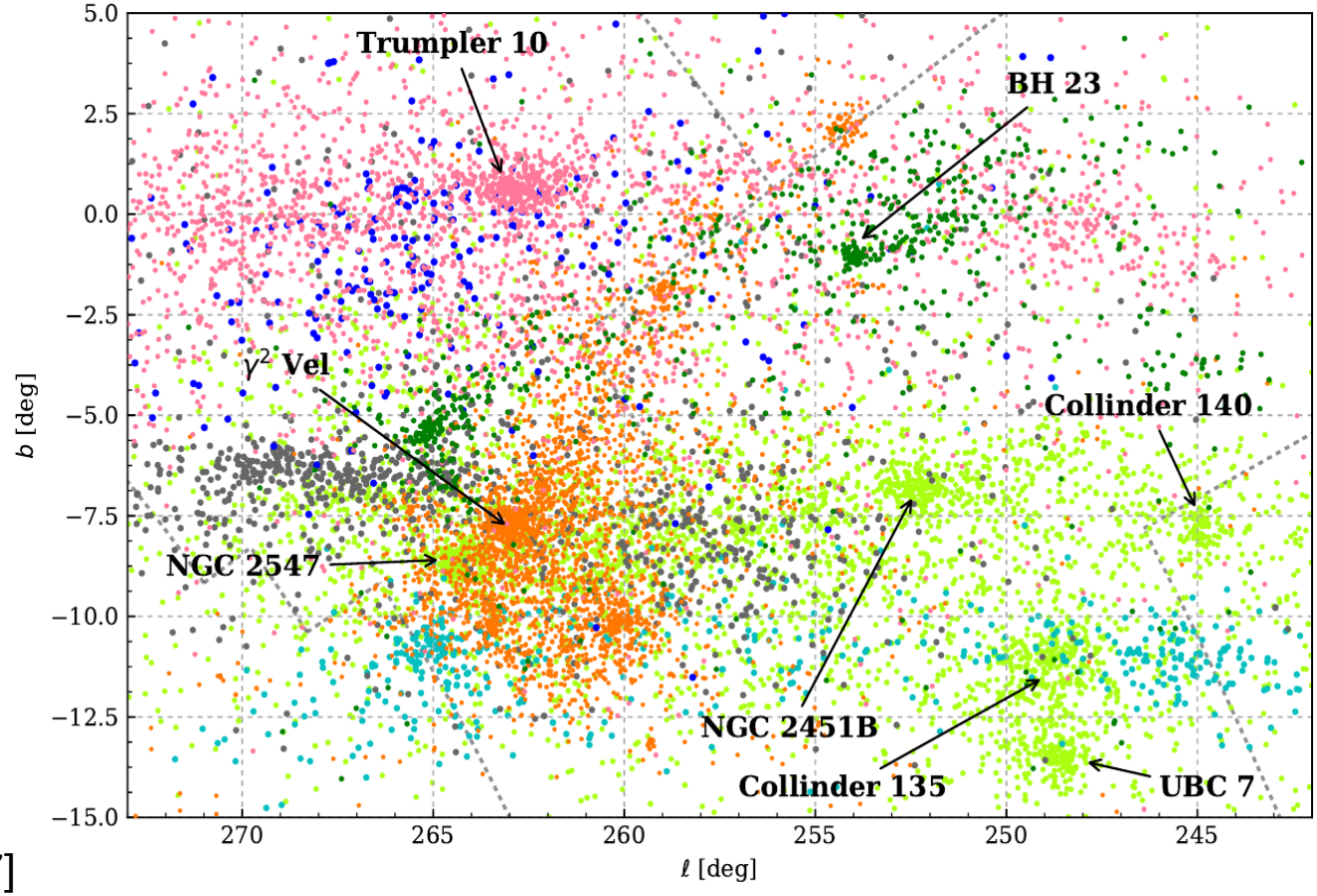
Applied UPMASK to spot kinematically compact but spatially extended "populations" (groups? teams?)

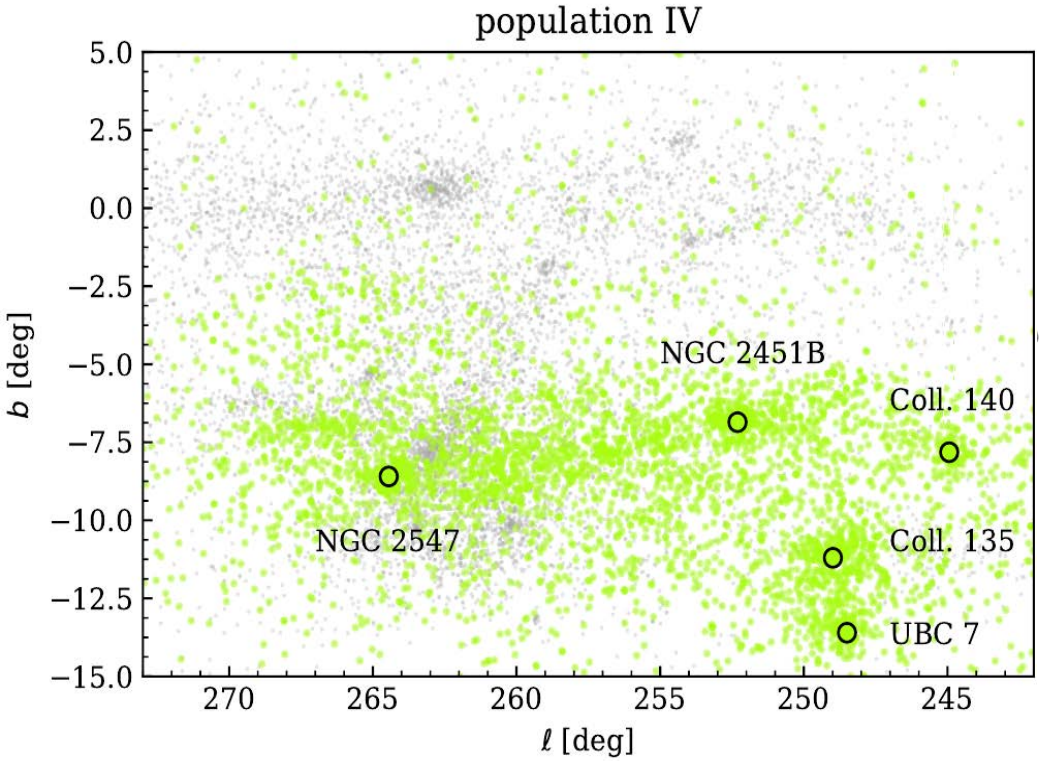
The stars in this volume of space are clustered in seven main kinematic groups, each one showing spatial and kinematic substructure.

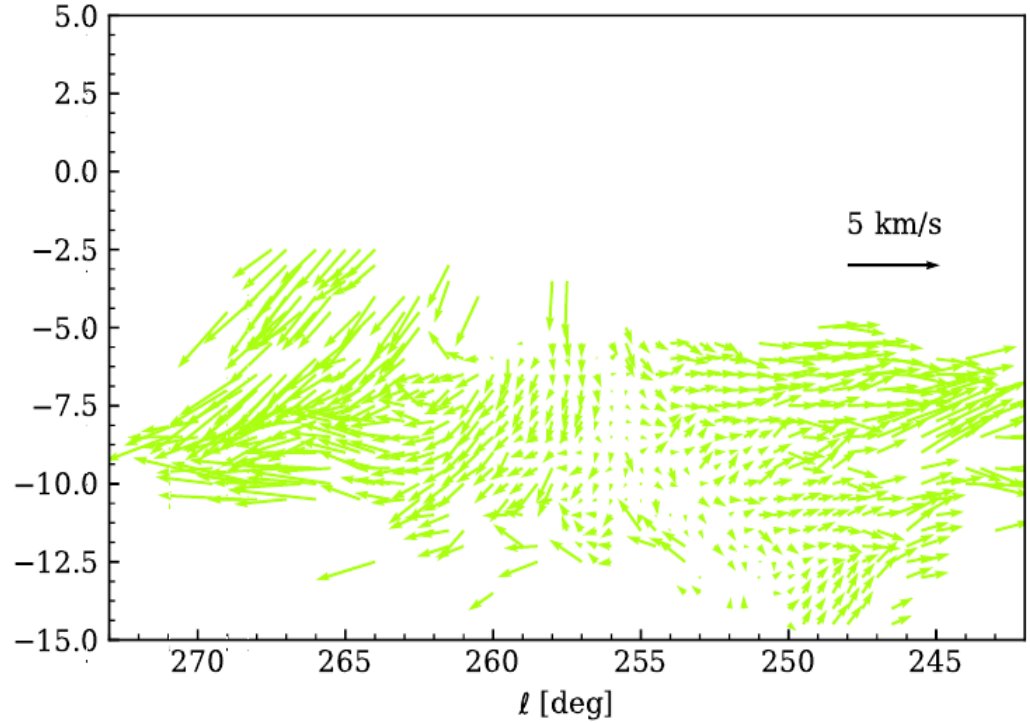
"Vela OB2" is the youngest of these groups (~10 Myr).
The others are 20 – 50 Myr old (all still have pre-main sequence stars).
(all of them host bright blue stars too, so I see no objective reason to call some "clusters" and others "OB associations")

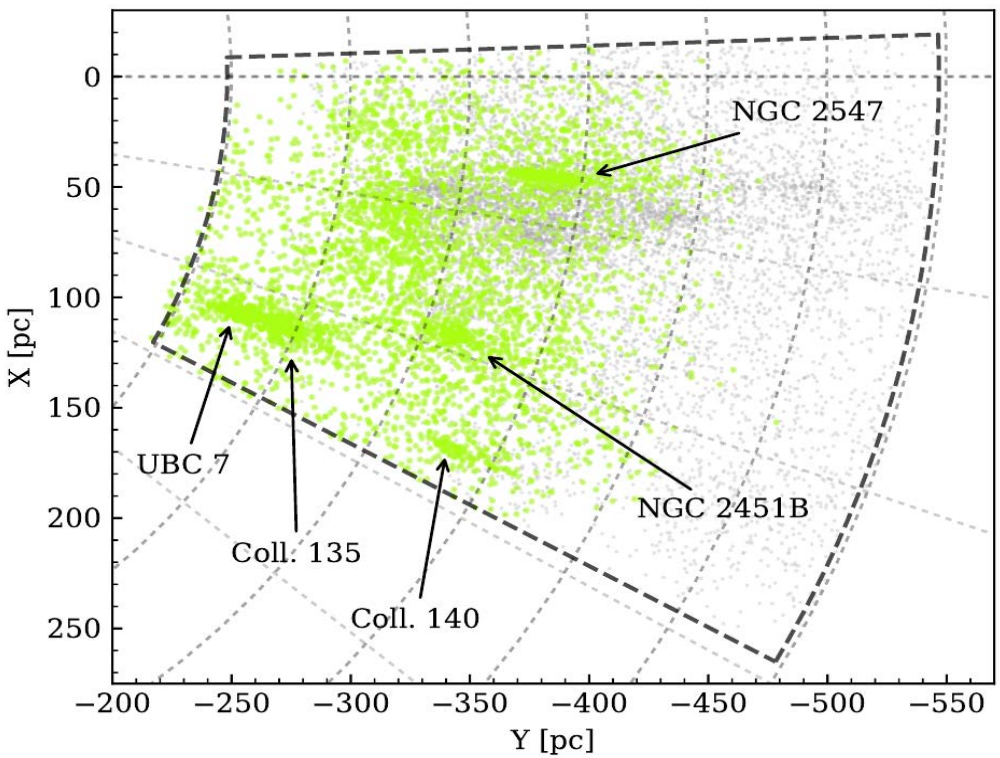




[Cantat-Gaudin et al. 2019, A&A 626 17]







These results show that NGC 2457, NGC 2451B, Collinder 140, Collinder 135, and UBC 7 are all siblings (~35 Myr).

They are physically connected, share a common space velocity, and their pre-main sequence stars overlap in a colour-absolute magnitude diagram.

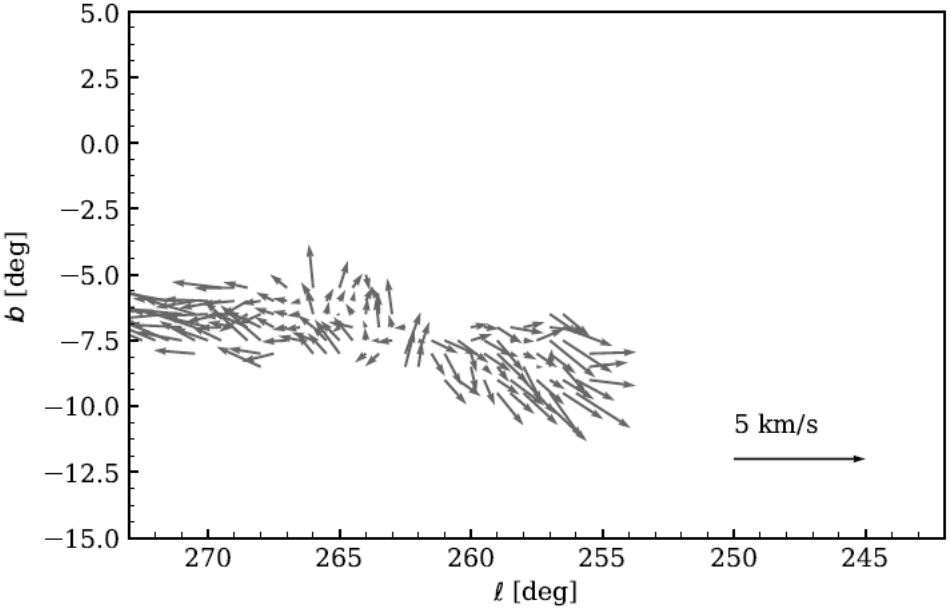
Not sure whether any of the clusters is actually bound. Maybe they are all dispersing?

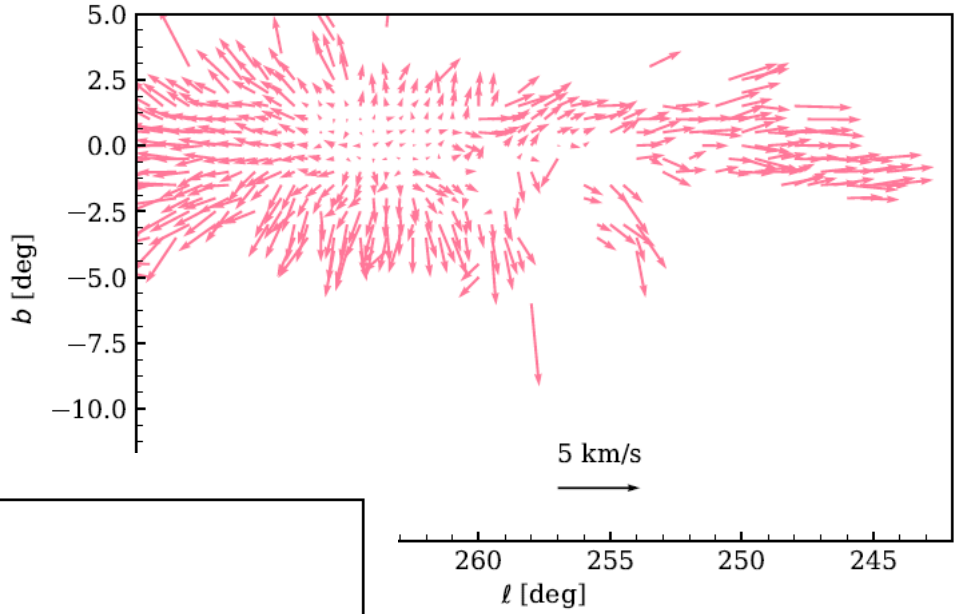
[Cantat-Gaudin et al. 2019, A&A 626 17]

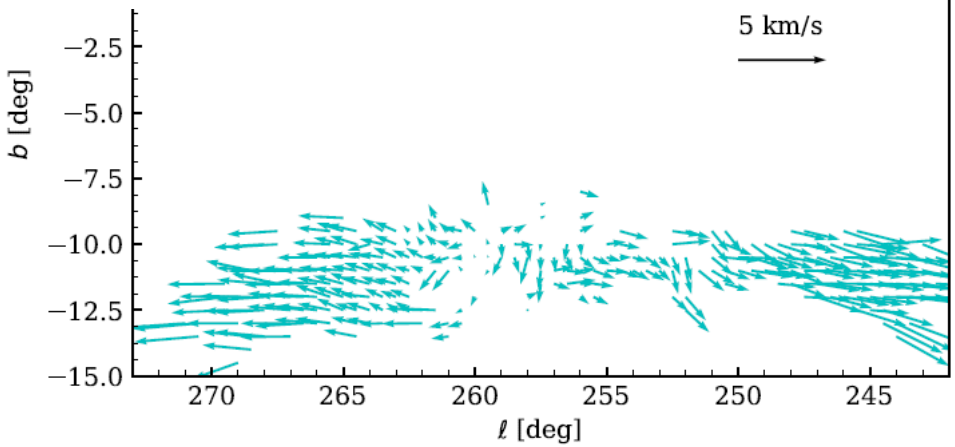
Overall expansion

All seven “populations” are expanding. Linear expansion coefficients seem higher along the Galactic plane than in the perpendicular direction: effect of Galactic rotation/shear?

Linear expansion along the line of sight too, but we only have radial velocities for a small subsample: this will change in Gaia DR3!

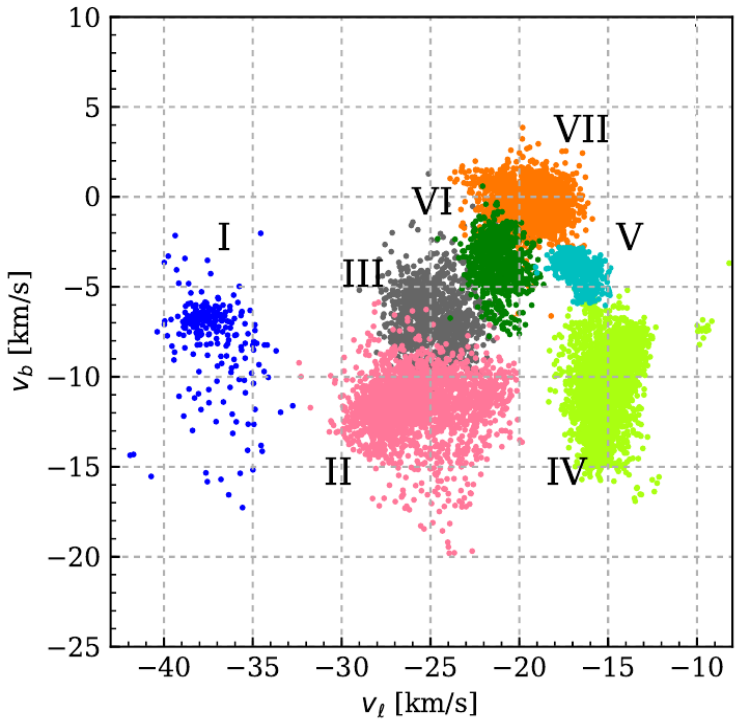


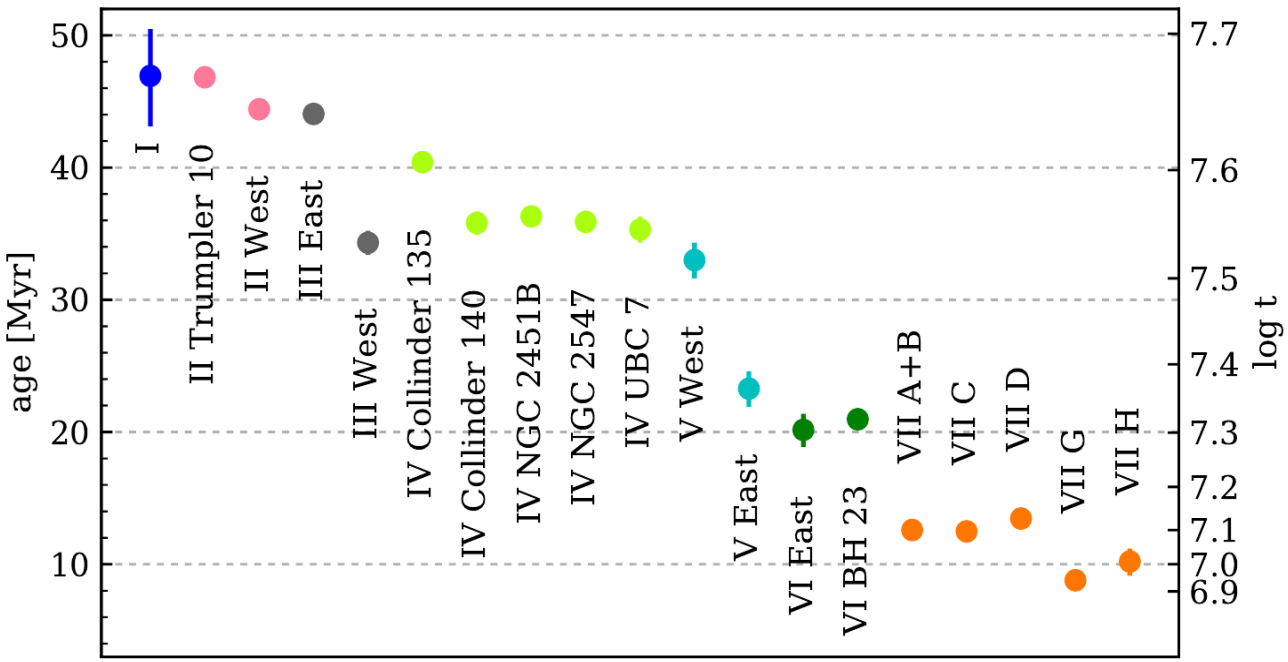




Groups with similar kinematics have similar ages

Ages estimated for the pre-main sequence stars of individual clumps, using PARSEC isochrones and Gaia DR2 photometry.





[Cantat-Gaudin et al. 2019, A&A 626 17]

Suggests a complex time line with **bursts of star formation**, and mechanisms shaping the spatial and velocity distribution.

The level of detail and the dimensionality we can reach with Gaia DR2 allows for good comparisons with computer simulations!

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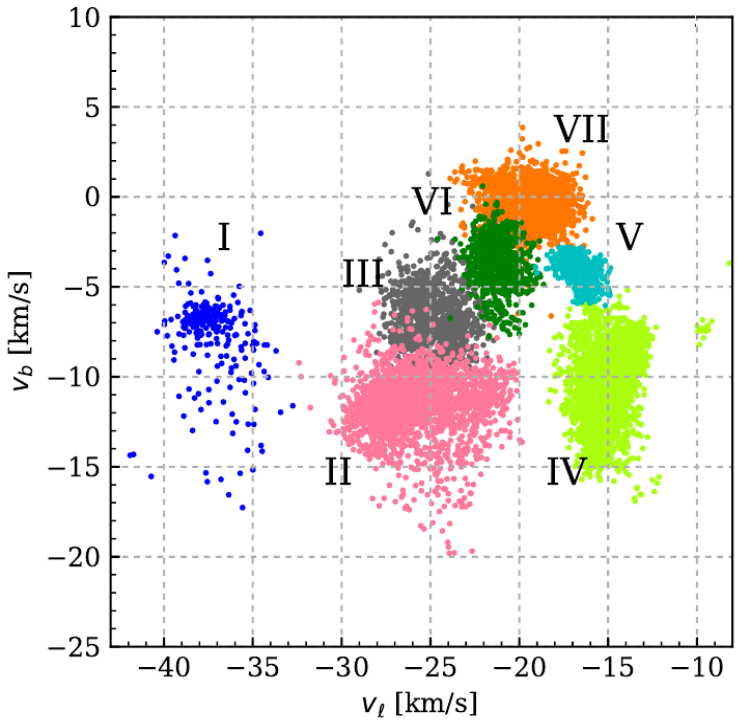

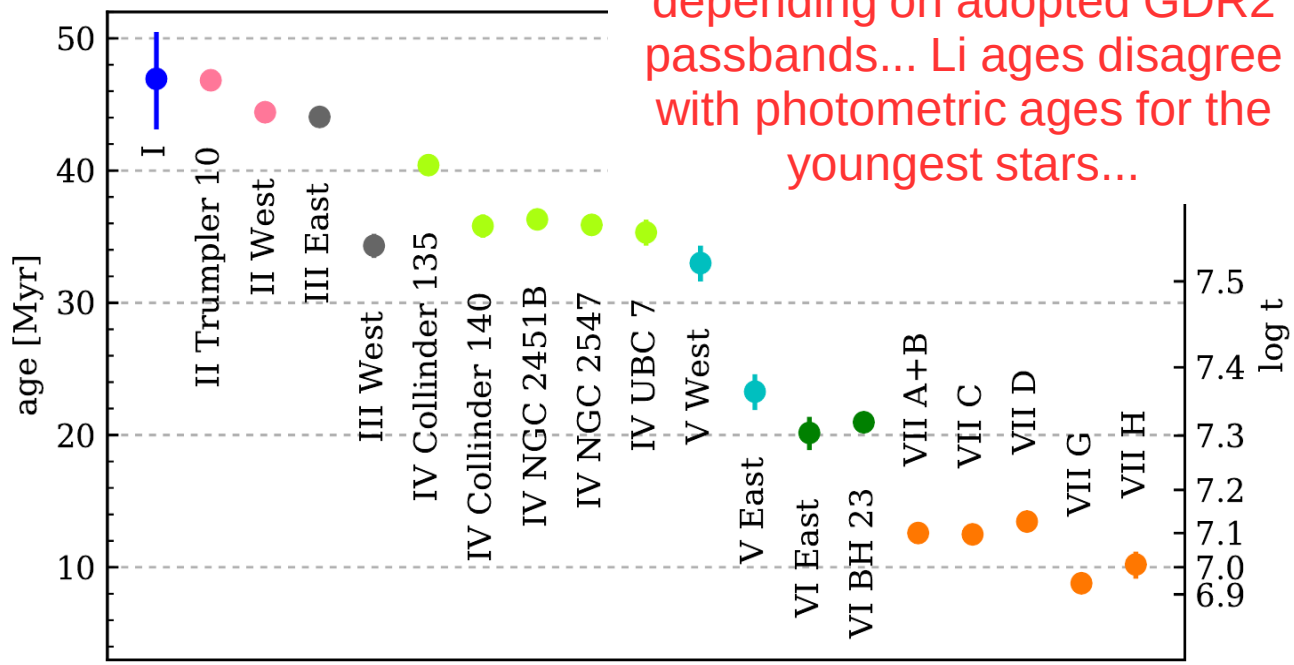

offset of +0.05 or +0.10 in log(t) depending on adopted GDR2 passbands... Li ages disagree with photometric ages for the youngest stars...

[Cantat-Gaudin et al. 2019, A&A 626 17]

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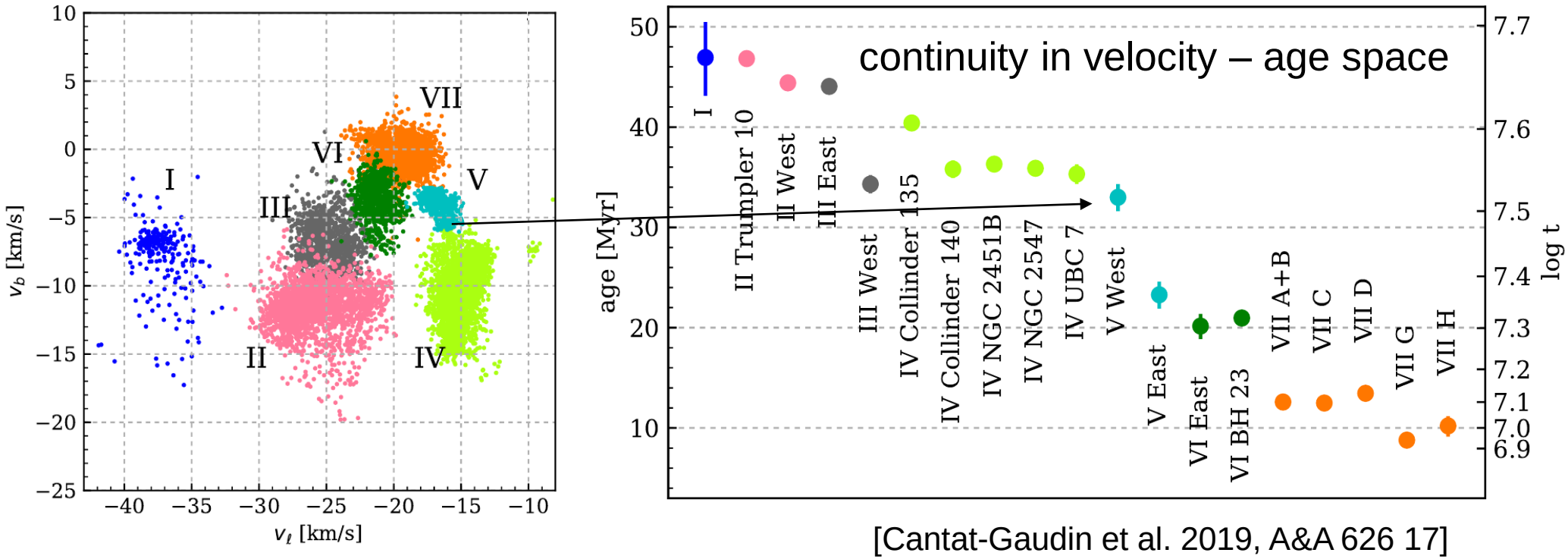

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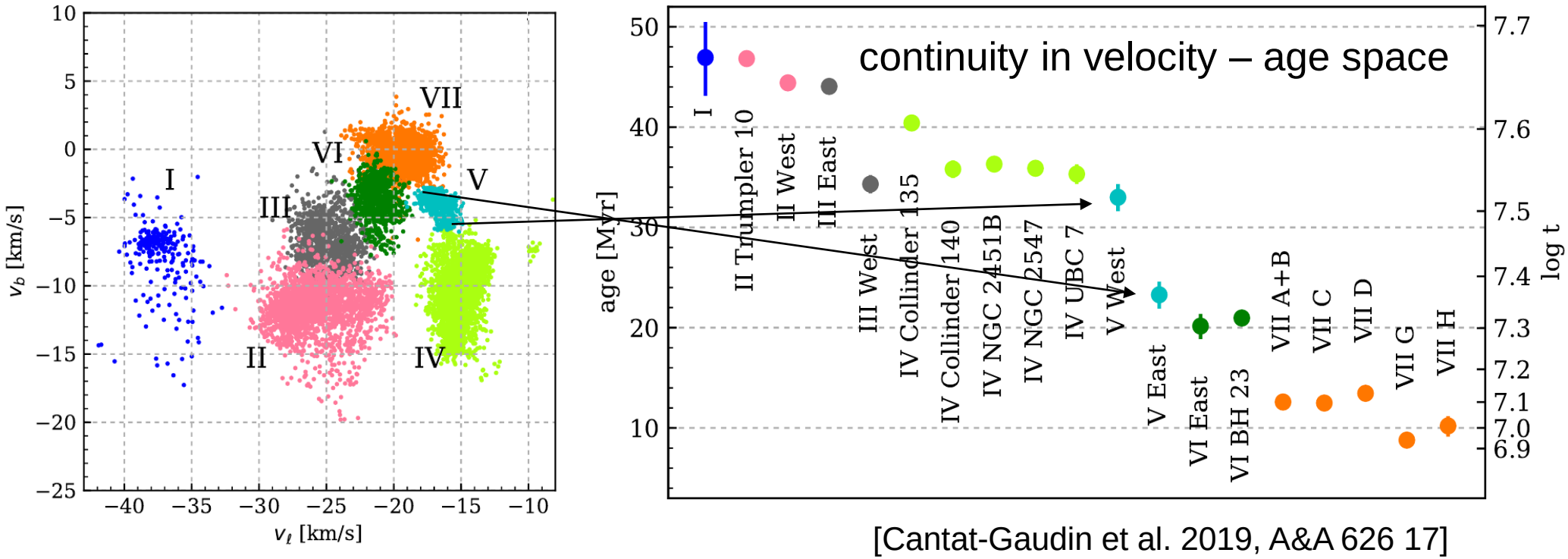

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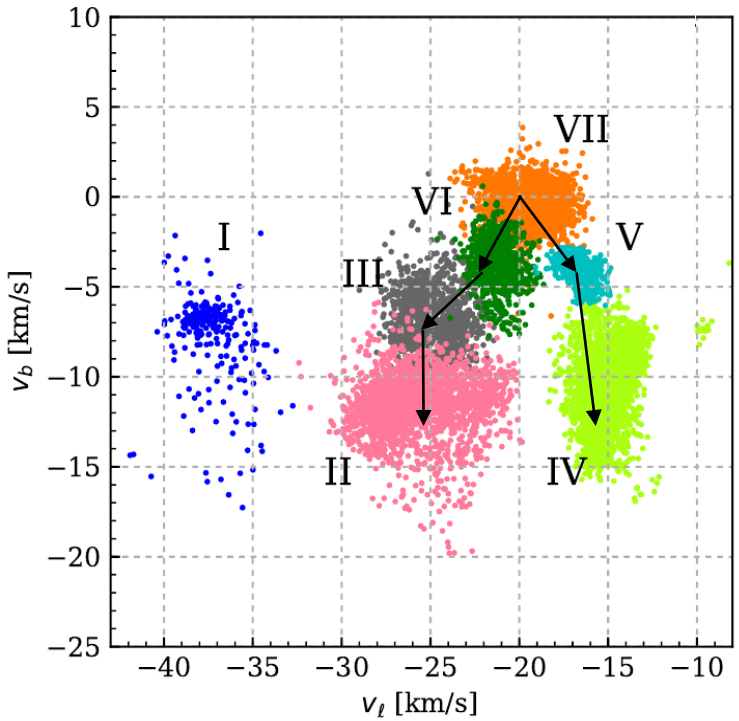

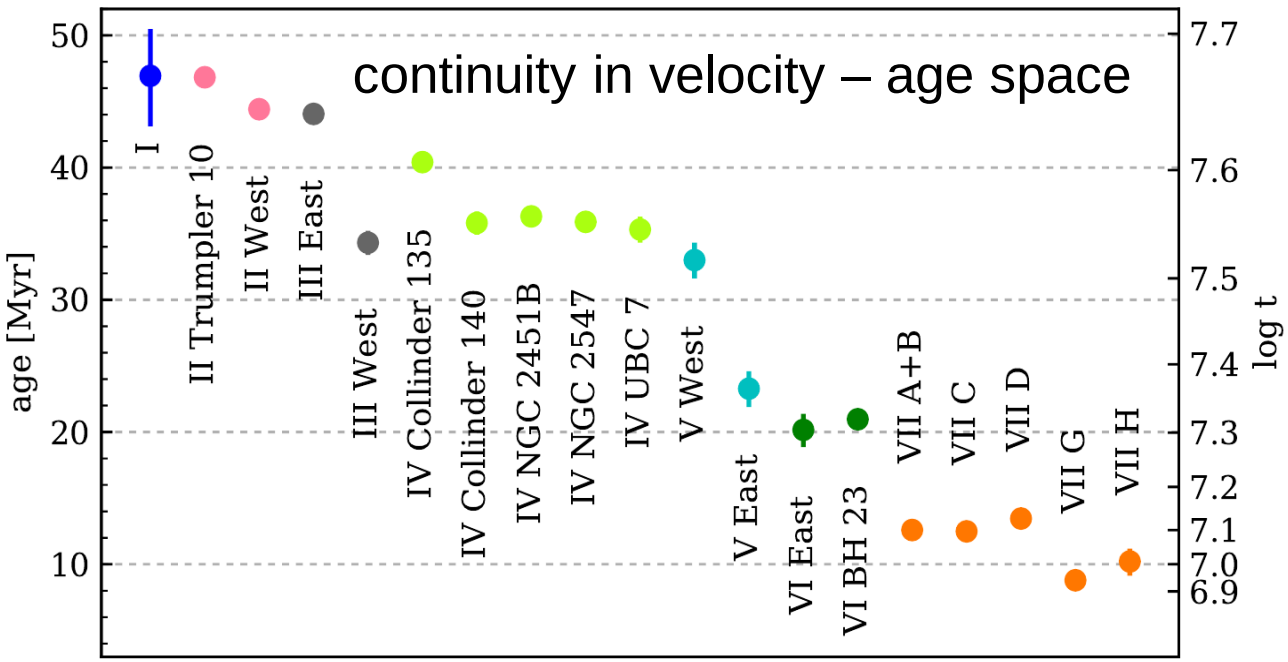

[Cantat-Gaudin et al. 2019, A&A 626 17]

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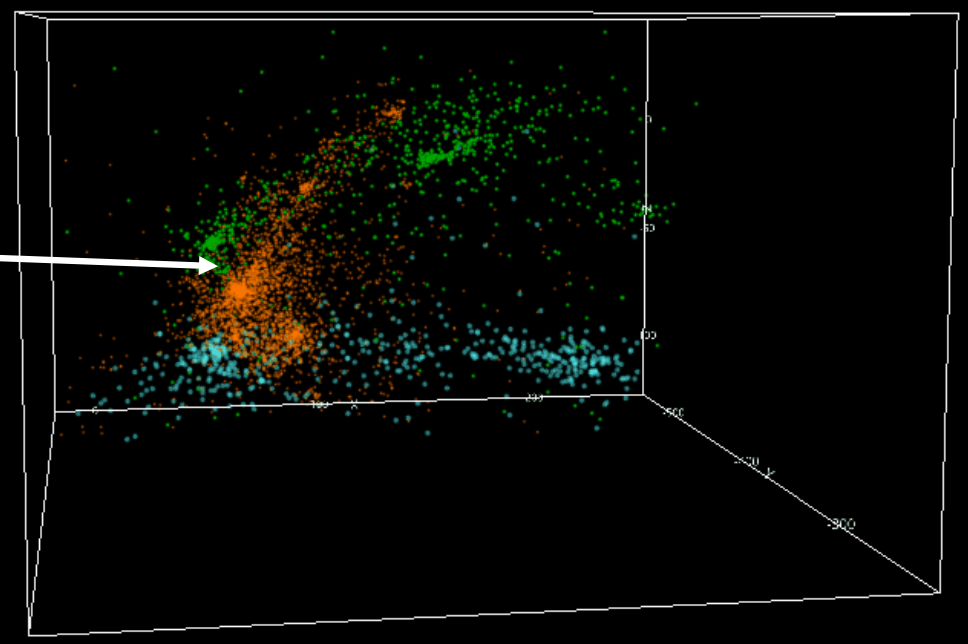
Tentative 3D visualisation of the three youngest populations

The stars shown are 10 – 20 Myr old

Not pictured:
The newly discovered "population III" is ~40 Myr old groups fits exactly in this cavity

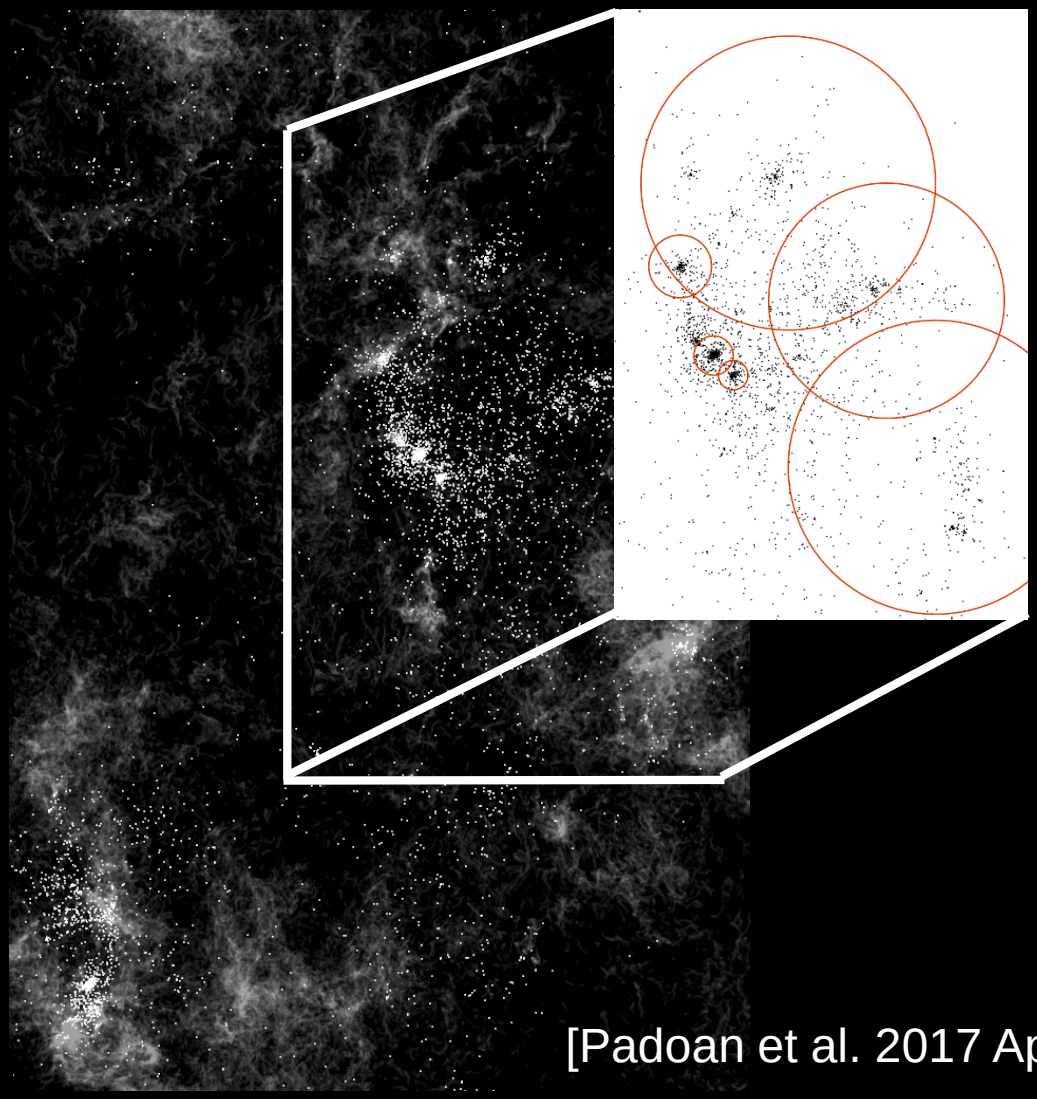


Did a supernova event in the (now) 40 Myr old population trigger the formation of stars around it?

Produced with Glue (Beaumont et al. 2015; Robitaille et al. 2017)

One possible mechanism: Supernova-driven turbulence

Padoan et al. (2017) simulate star formation in a 250pc cube.
They form both compact clumps (potentially bound) and dispersed stars.
Stellar formation happens in bursts.
Age groups can be compact and kinematics but spatially extended.



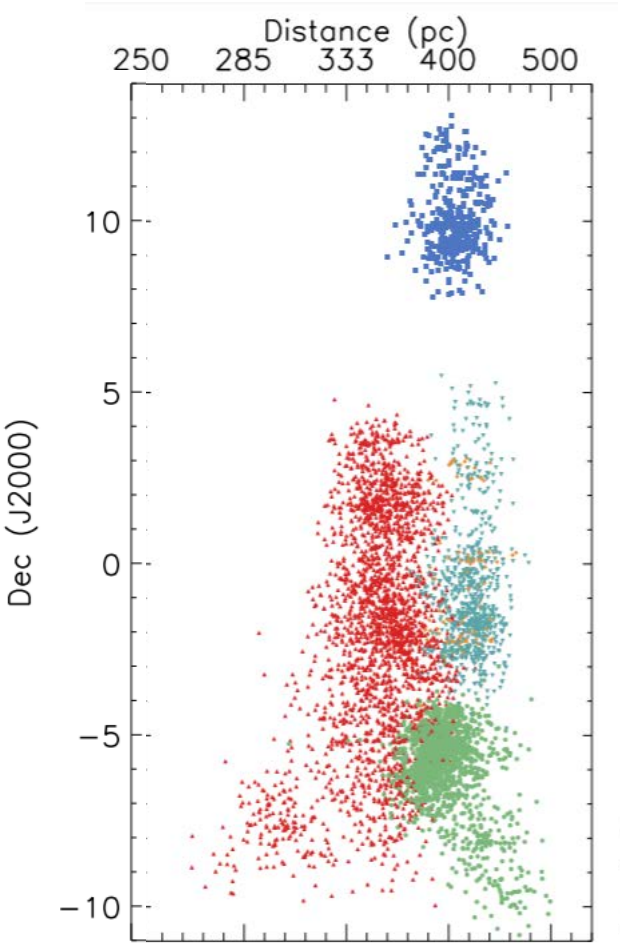
[Padoan et al. 2017 ApJ 840 48]

With Gaia DR2 we can compare observations to simulations using more than just 2D distributions projected on the sky.

We have 3D positions, 3D velocities, and can perform more precise selections.

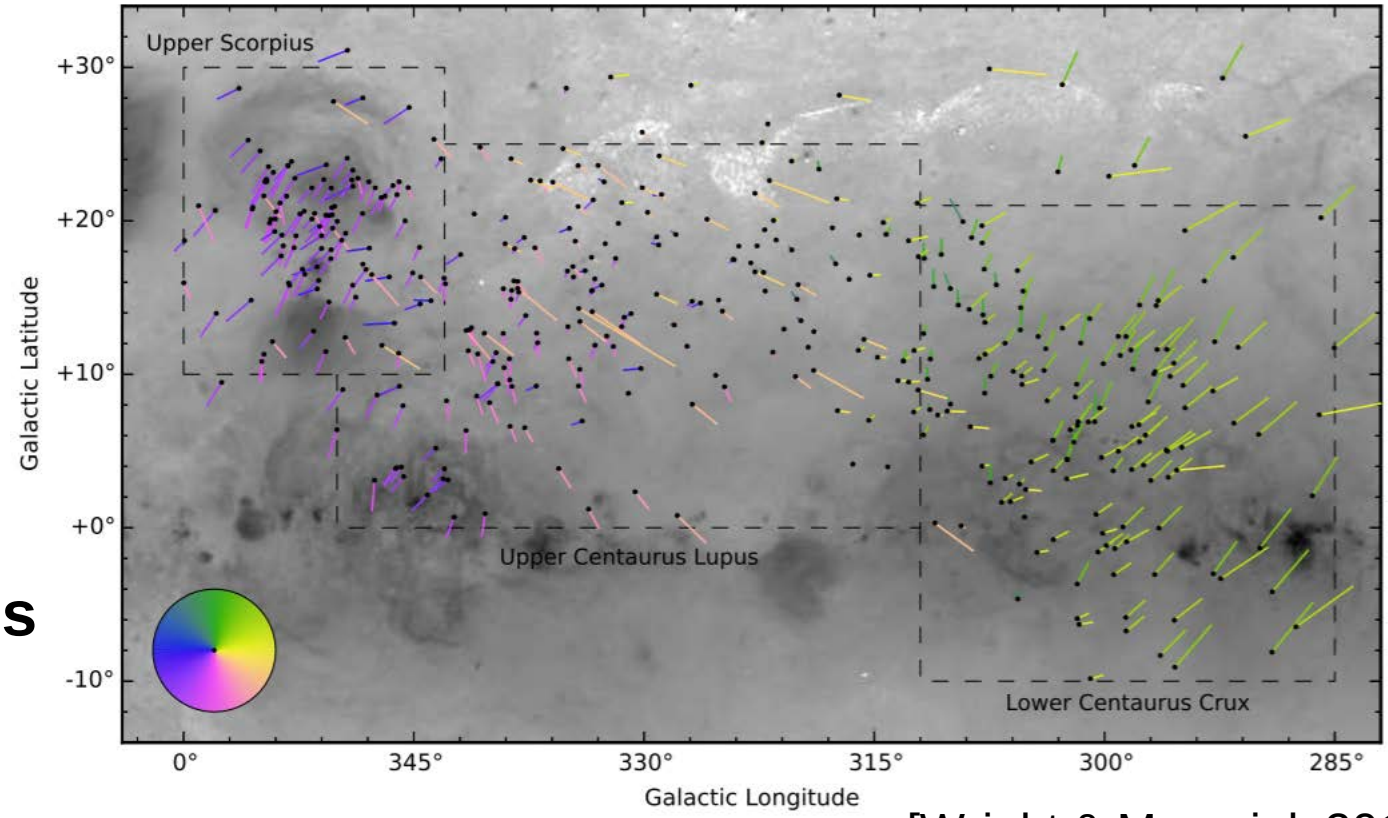
Age determinations of pre-main sequence stars from photometry are not optimal though, especially from Gaia photometry only...

The morphology of Vela seems different from other nearby stellar complexes



[Kounkel et al. 2018]

In **Orion** the fragments are more distinctly separated? Maybe it is just an age or scale effect.



Scorpius-Centaurus shows no obvious signs of expansion.

[Wright & Mamajek 2018]

The morphology of Vela seems different from other nearby stellar complexes

What makes these complexes appear so different?
The initial morphology of the parent cloud? Its scale?

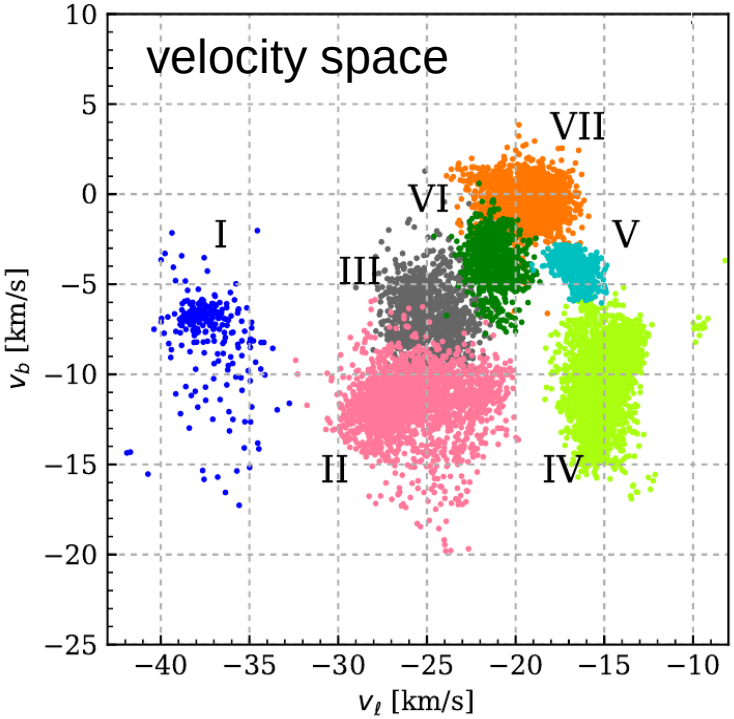
The random onset of the first supernova: deep within the cloud vs on the edge?

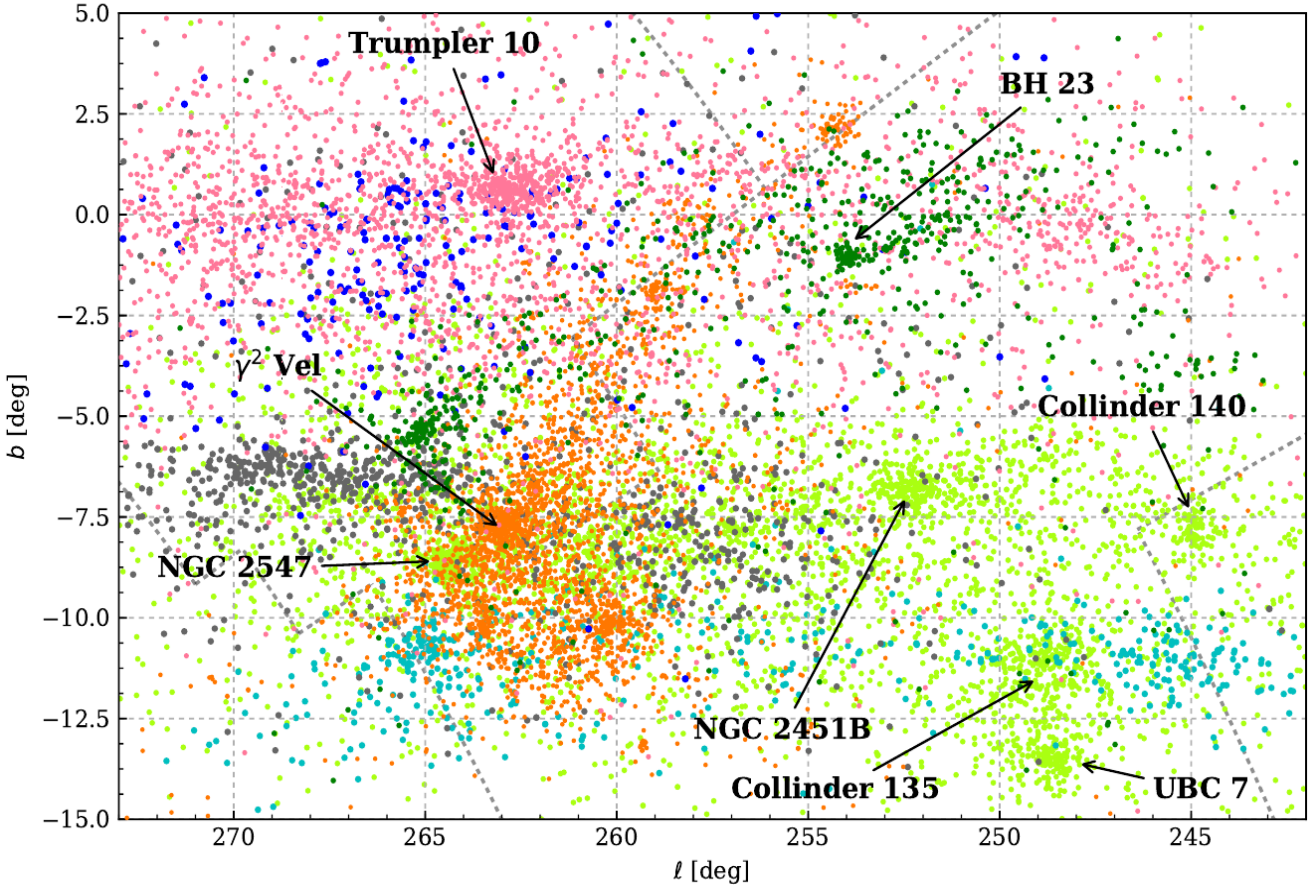
Do some complexes form a larger proportion of bound clusters than others?

Summary

1) The **“Vela OB2 association”** is just the result of the distribution of the bright blue stars of these seven groups: it appears diffuse and somehow centered on Gamma2 Velorum, but it is not a single distinct physical entity.

2) It is unclear whether any of the dense clumps is going to become a “traditional” bound open cluster.





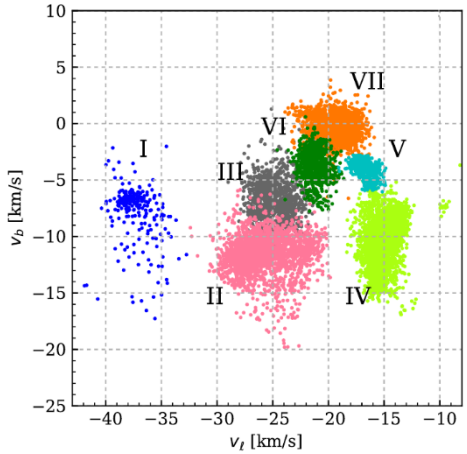
Summary

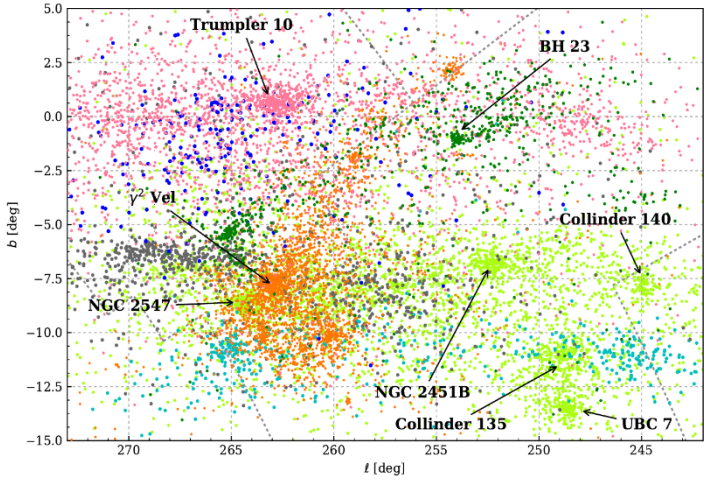
1) The **“Vela OB2 association”** is just the result of the distribution of the bright blue stars of these seven groups: it appears diffuse and somehow centered on Gamma2 Velorum, but it is not a single distinct physical entity.

2) It is unclear whether any of the dense clumps is going to become a “traditional” bound open cluster.

3) The entire stellar complex looks like the result of star formation in a supernova-sustained turbulent cloud.

4) With Gaia DR2, even observers can have cool 3D animations to show! This also makes the diagnostics and comparisons with numerical simulations more precise and convenient.





Summary

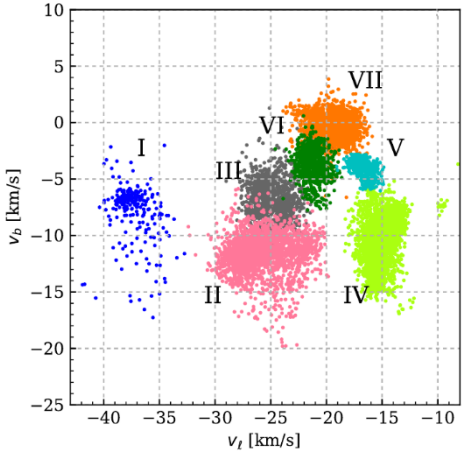
1) The **“Vela OB2 association”** is just the result of the distribution of the bright blue stars of these seven groups: it appears diffuse and somehow centered on Gamma2 Velorum, but it is not a single distinct physical entity.

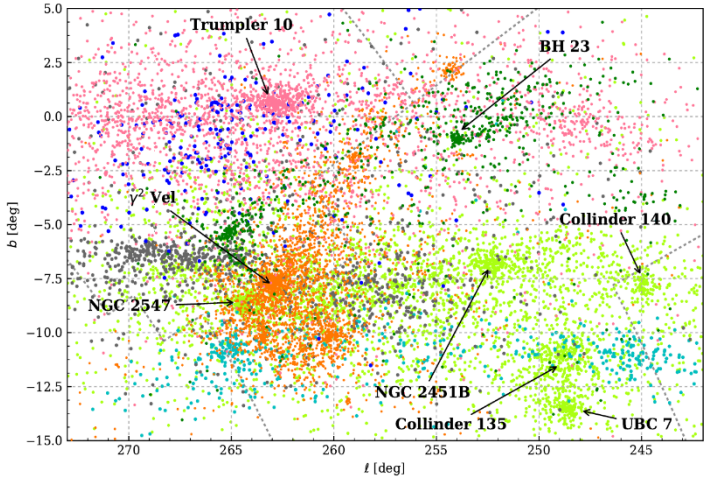
2) It is unclear whether any of the dense clumps is going to become a “traditional” bound open cluster.

3) The entire stellar complex looks like the result of star formation in a supernova-sustained turbulent cloud.

4) With Gaia DR2, even observers can have cool 3D animations to show! This also makes the diagnostics and comparisons with numerical simulations more precise and convenient.

Thank you!





My approach to clustering

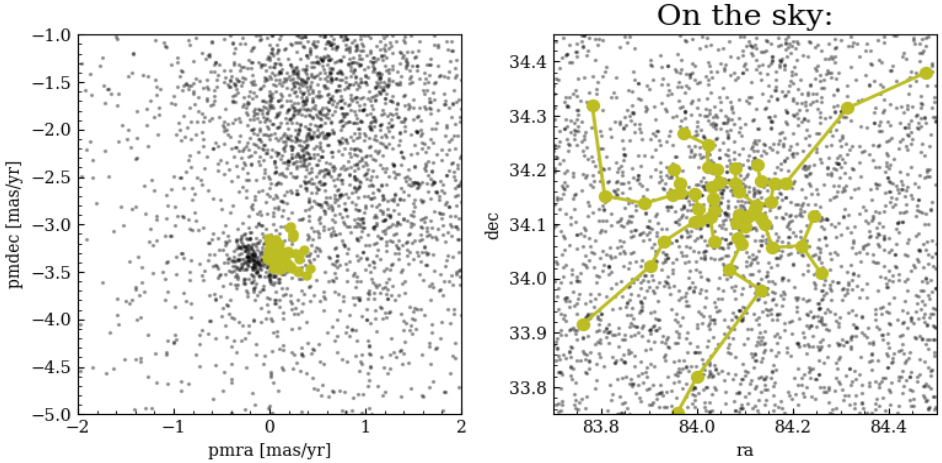
I use the procedure UPMASK (Krone-Martins & Moitinho 2014):

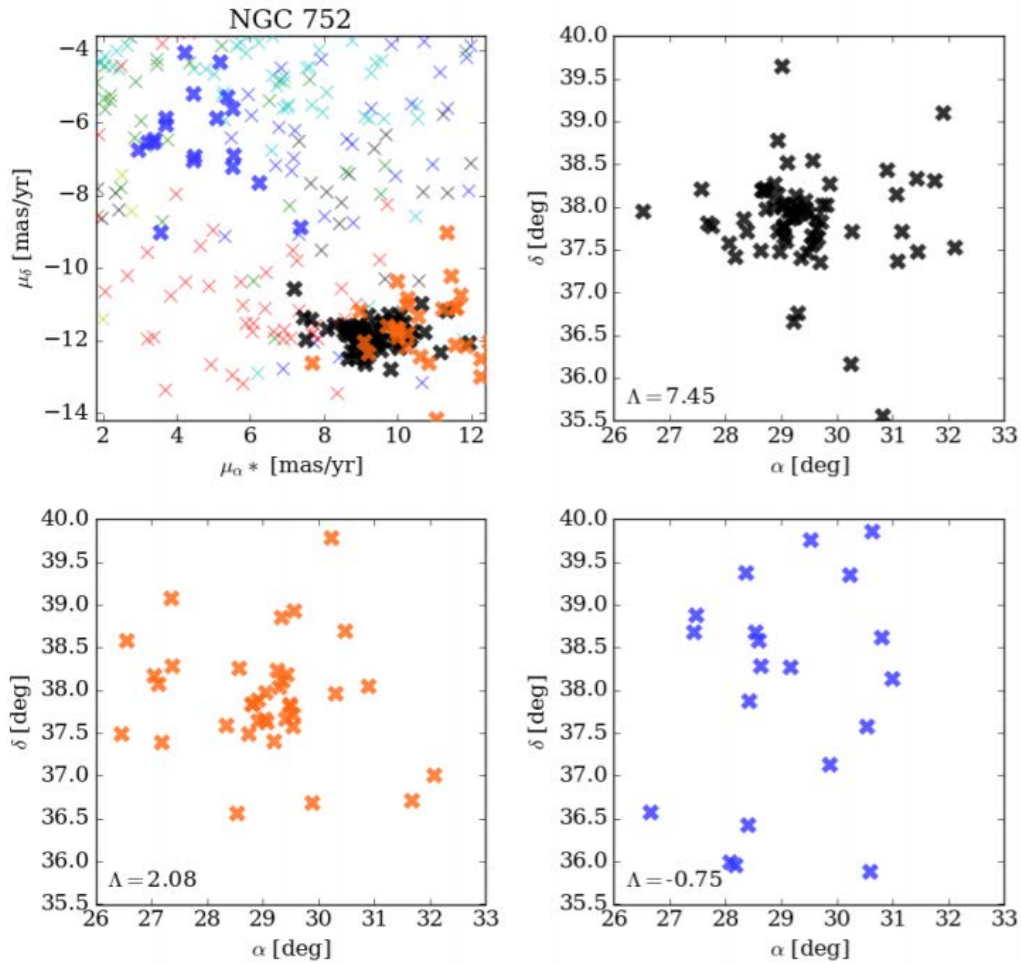
1) Group stars according to their proper motions and parallaxes (I use k-means clustering)

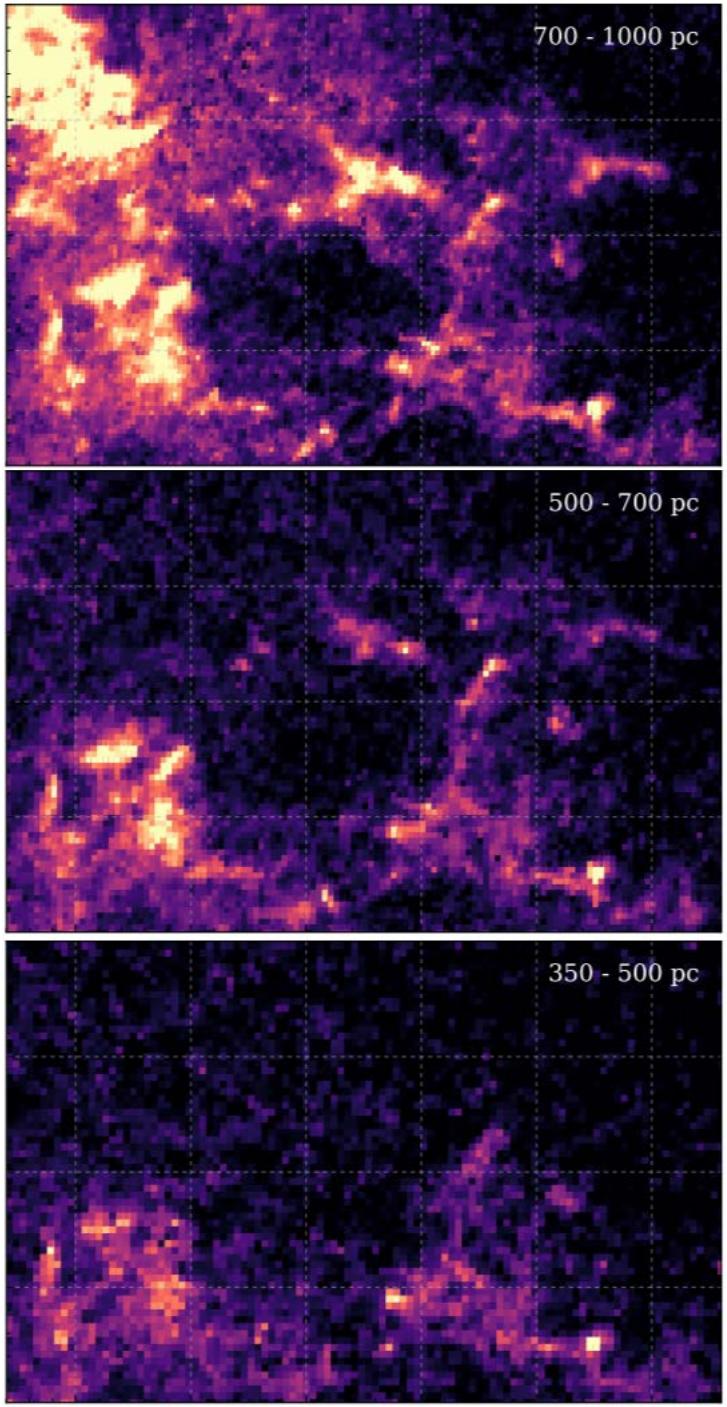
2) Quantify how much their projected spatial distribution differ from a random uniform distribution (I use the median length of a minimum spanning tree, similar to the Allison et al. mass segregation diagnostic)

I like this approach because it does not need any assumption on the morphology.

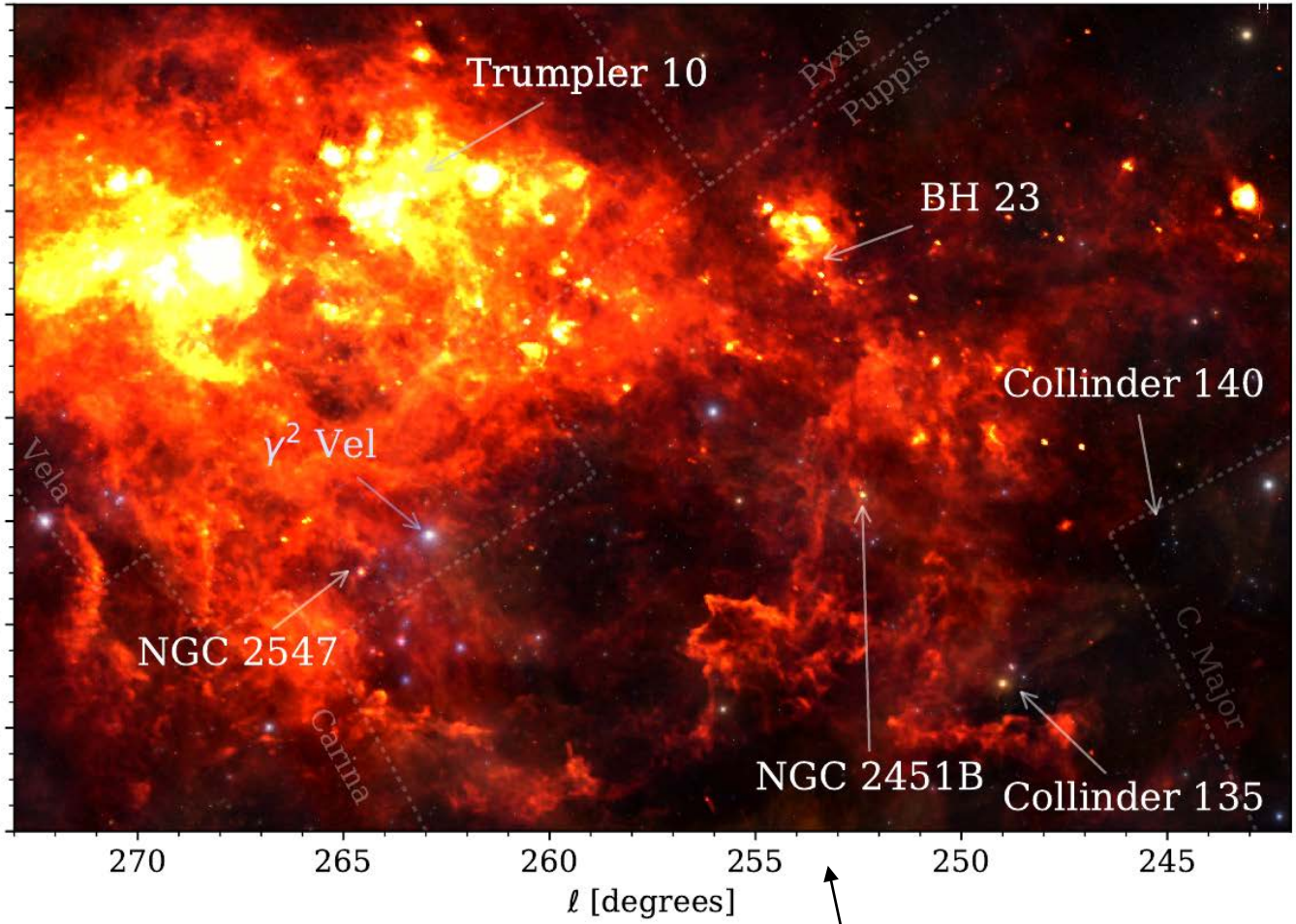
You can shuffle the data within the nominal uncertainties and compute a "membership probability".







Av tomography from Gaia DR2 extinctions



IRIS (infrared emission)